March 2019

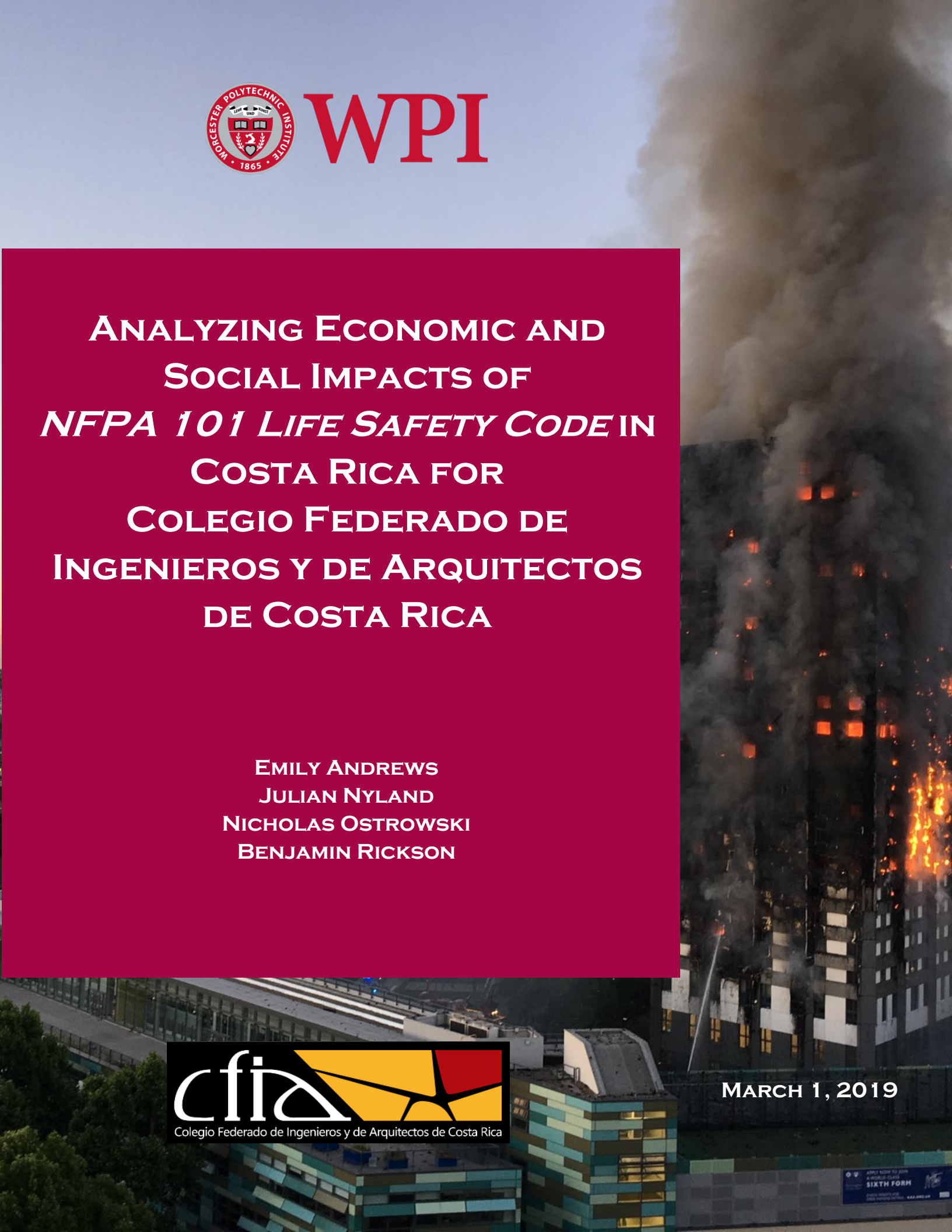
Analyzing Economic and Social Impacts of NFPA 101 Life Safety Code in Costa Rica

Benjamin Martin Rickson
Worcester Polytechnic Institute

Emily Catherine Andrews
Worcester Polytechnic Institute

Julian Joshua Nyland
Worcester Polytechnic Institute

Nicholas J. Ostrowski
Worcester Polytechnic Institute



WPI

Analyzing Economic and Social Impacts of *NFPA 101 Life Safety Code* in Costa Rica for Colegio Federado de Ingenieros y de Arquitectos de Costa Rica

Emily Andrews
Julian Nyland
Nicholas Ostrowski
Benjamin Rickson

cfia
Colegio Federado de Ingenieros y de Arquitectos de Costa Rica

March 1, 2019

Analyzing Economic and Social Impacts of *NFPA 101 Life Safety Code* in Costa Rica for Colegio Federado de Ingenieros y de Arquitectos de Costa Rica

An Interactive Qualifying Project Submitted to the Faculty of *Worcester Polytechnic Institute* in partial fulfillment of the requirements for the Degree of Bachelor of Science

Submitted By:
Emily Andrews
Julian Nyland
Nicholas Ostrowski
Benjamin Rickson

Date:
March 1, 2019

Report Submitted to:
Worcester Polytechnic Institute
James Chiarelli and Alex Sphar PhD, Co-Advisors
Colegio Federado de Ingenieros y de Arquitectos de Costa Rica, Sponsor
Arq. Hernan A. Hernandez, Sponsor Coordinator

Abstract

The purpose of this project was to investigate how adhering to *NFPA 101 Life Safety Code* impacts building professionals and the percent increase it has on the cost of construction. We accomplished this by analyzing construction budgets and interviewing industry professionals to obtain a holistic view of *NFPA 101* knowledge. The project determined that NFPA code compliance increases cost by 3%-6%. This project also resulted in recommendations for improving NFPA knowledge, clarifying NFPA regulation and improving inspection processes.

Acknowledgments

We would like to express our sincere thanks to our sponsor, the Colegio Federado de Arquitectos y Ingenieros de Costa Rica, in particular the Life Safety Committee for their constant support and dedication to our project. We would also like to thank Hernán A. Hernández for his guidance and technical knowledge, which was crucial throughout our project.

We would like to thank Professor Melissa Belz for her hard work and dedication to developing engaging projects at both the San Jose, Costa Rica project site as well as the Monteverde, Costa Rica project site. Through her work, we have had years of successful, interesting projects at both Costa Rica project sites.

We would also like to thank Doña Marcela Music and Don Jim Music for their hard work in organizing this project and enabling us to work with the CFIA. Their ties to Worcester Polytechnic Institute in Costa Rica have led to years of successful project work and to new sponsor relationships, as seen this year with the CFIA.

Additionally, Professor Milosh T. Puchovsky, WPI Fire Protection Engineering Professor, deserves our thanks for meeting with the group prior to our departure and providing essential information regarding NFPA code compliance and enforcement. We would also like to thank the interviewees we met with in Costa Rica, who, while not named in this report, were essential to its success.

We would like to thank our advisors, James Chiarelli and Alex Sphar, for their guidance, support and knowledge throughout ID2050 and continuing through our time in Costa Rica. They dedicated hours to our project and to providing valuable feedback, which enabled us to complete this report and presentation to the best of our ability.

Finally, we would like to thank Worcester Polytechnic Institute for providing us with this opportunity to successfully complete our project in Costa Rica.

Executive Summary

Building fires have long been a concern of both building owners and occupants. To mitigate this, various groups have worked to develop fire prevention measures that hold building owners to certain standards to prevent fires. Fire protection systems implemented and sustained in buildings improve the life safety of occupants during instances of fire. The National Fire Protection Association (NFPA) developed fire prevention measures for buildings and synthesized these into codes and standards, which Costa Rica adopted in 2005 after public backlash resulting from a major hospital fire. While the NFPA codes were adopted almost 15 years ago, many buildings that have been constructed since their adoption are not in compliance with the NFPA codes, in particular the *NFPA 101 Life Safety Code*. This fire code focuses primarily on passive fire protection systems intended to preserve life and ensure safe evacuation from burning buildings. Our sponsor believes that the lack of NFPA code adherence is due to professionals' beliefs that it is too expensive, and we were asked to investigate this important issue in hopes of shedding light on the controversy.

Our goal was to work with the Colegio Federado de Ingenieros y de Arquitectos de Costa Rica [Federated College of Engineers and Architects] Life Safety Committee in San José, Costa Rica to show that compliance with *NFPA 101 Life Safety Code* is not a large financial burden on construction budgets. This was accomplished by determining a percent of total budget dedicated to fire protection measures for buildings that follow NFPA codes and buildings that do not. Understanding the social and economic impacts of the application of *NFPA 101* on stakeholders was essential. The CFIA Life Safety Committee aspires to improve and sustain the application of *NFPA 101* in Costa Rica to ensure life safety of occupants. Our findings and recommendations challenged professionals' beliefs that NFPA 101 code compliance leads to great expense and addressed social and economic impacts of fire code implementation and sustainability on stakeholders.

Project Goals

1. Understand current NFPA code application, infrastructure and enforcement procedures in Costa Rica.
2. Analyze construction budgets to determine the overall outstanding costs of a building that follows NFPA codes and a building that does not.
3. Gauge the needs and motivations of the building architects, engineers, vendors and occupants to determine opinions and social impacts of NFPA codes.
4. Provide evidence that following the NFPA codes is not a large financial burden and justify whether incentives for NFPA code compliance are needed.

We gathered information regarding the background and history of the NFPA codes in Costa Rica through research and interviews with a WPI Fire Protection Engineering professor, Arq. Hernán Hernández, our sponsor representative and El Cuerpo de Bomberos (Costa Rican Fire Department). Upon arriving to Costa Rica, we analyzed various construction budgets provided to us be the CFIA to determine the financial impact caused by implementing fire protection measures in buildings.

Our next objective required interviews with various professionals in Costa Rica, including architects, engineers, material vendors, construction professionals and developers. We asked

questions regarding their knowledge and background in NFPA codes, their opinions on implementing NFPA codes, and other questions relevant to their specific background. To achieve our final objective, we analyzed the responses from all the interviews we conducted, looking for themes and similarities throughout. We also looked at our budget analyses to see the budget impact and whether it would greatly increase the cost of construction. From these steps, we determined our findings and recommendations.

The main deliverables for the project were to find the percentage of total construction cost of fire protection systems for a building and a cost per square meter of a *NFPA 101* compliant building as compared to a non-compliant building. Concurrently, we explored the impacts and complications of using *NFPA 101* for stakeholders in the industry. We conveyed this information to the CFIA Life Safety Committee with a presentation and report that we hope will lay the groundwork for future improvements in fire safety in Costa Rica.

Findings for *NFPA 101* Application

Construction Budget Analysis

We discovered that the inclusion of fire protection measures in accordance with *NFPA 101 Life Safety Code* causes a budget increase of 3%–6 % of the total construction budget, with 2%–4% increase for the passive system and 1%–5% for the active system. While this may seem expensive, most construction budgets are in millions of dollars, and 3%–6% is a very small increase, especially when considering the benefits of installing fire protection, like minimizing fire damage in buildings and most importantly saving the lives of the occupants and firefighters. During our analysis, we considered the active system, as well as parts of the passive system including doors, walls, and ceilings. The major issues with this finding are that every professional we spoke with believes that fire protection measures cause a significant cost increase, despite never doing their own budget analysis. Additionally, fire protection can cause an increase in cost if there are any issues in compliance caused by either a lack of knowledge from the professional or from conflicting information from the Bomberos.

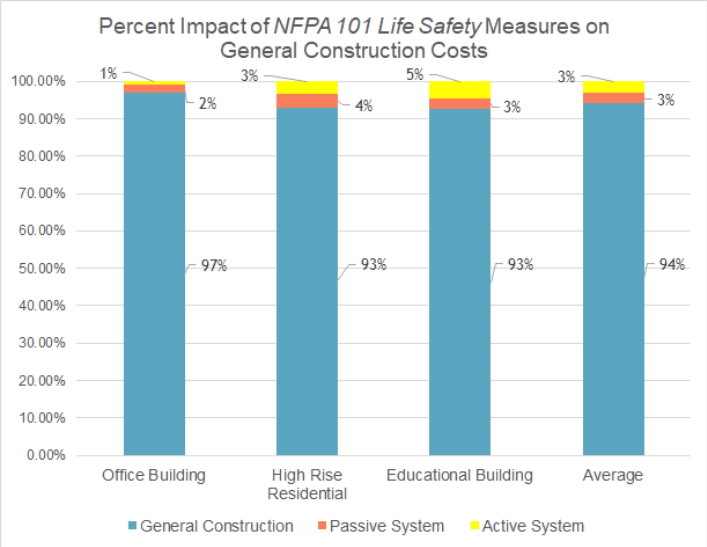


Figure 1. Graph Based on CFIA Provided Construction Budgets showing percent increase caused by Fire Protection measures

Lack of NFPA Education

We discovered that the problem of following the NFPA codes is not with building professionals ignoring the codes and refusing to incorporate them into their designs and buildings, but with the scarcity of knowledge of the NFPA codes in Costa Rica. More

specifically, universities fail to educate architects about passive systems, which include the designs of walls, doors, and ceilings and are mentioned throughout the *NFPA 101 Life Safety Code.* Various architects revealed to us that they had no knowledge of *NFPA 101* until some of their work failed after being inspected by the Bomberos. We discovered that the availability of NFPA code knowledge extends from NFPA instructed courses, CFIA prepared courses, and courses offered by material distributors that vary in cost from $500 to $1100 each. We found that very few architects and engineers take advantage of these resources to increase their knowledge of *NFPA 101,* which negatively impacts the building quality regarding fire protection methods.

Conflicting Information Between Bomberos Manual and NFPA Codes

The Bomberos introduced their Manual some time after the NFPA codes were adopted countrywide. The purpose of the Manual is to act as an explanatory manual, based on the NFPA standards. The Manual is not originally intended to act as a reference, but as a guide or handbook to explain some fire protection measures. However, we were told by the Bomberos that this Manual was an attempt to simplify and "tropicalize" some of the NFPA codes and that they were trying to make the Manual into a local code itself. The Bomberos anticipated updating the manual every year, however they are currently using the 2013 edition of the Manual, with a new edition expected to be published in 2019. The NFPA authorities have told the Bomberos many times that there is no need for the Manual to become a code, and that the NFPA codes will prevail over all others as long as it remains in law. Attempting to establish a national code would require consistent updating and testing that requires knowledge and manpower that the Bomberos simply do not have.

The conflicting information between these two sources is most prominent in the review of designs and inspections of work. We discovered that the Bomberos use the Manual to review construction documents before construction is started, then use the NFPA codes for inspections. Using these two sources interchangeably causes the Bomberos' work to be inconsistent and leads to many failed inspections that add time to the project. The Bomberos frequently call for equipment that is not needed or equipment that provides more protection against fire than is required, which can result in increased costs for the project.

Difficulties with Old Buildings Complying with NFPA 101 Life Safety Code

Buildings constructed before 2005 in Costa Rica do not comply with NFPA Codes. Renovating these old buildings to NFPA standards requires a substantial commitment of money, effort, and time. Specifically, it costs more money when comparing attempts at renovating old buildings and developing buildings. This is due to old buildings not being fitted for theses fire systems costing more money in attempts to comply with the NFPA codes. Old buildings usually have years of repair work and structures that are not suited for implementation of the NFPA codes, making them difficult to renovate following the codes. Renovation of old buildings also takes time, especially in large populous buildings and can affect the production and productivity. It is expensive, difficult, and time consuming to update old building in adherence with NFPA codes.

Availability of Fire-Rated Materials

Through our interviews and research, we were able to conclude that fire-rated materials are easily accessible in Costa Rica. Material vendors offer many types of fire-rated assemblies for project teams to utilize. Most of the materials are imported, but according to material vendors, it takes 6–8 weeks to arrive in the country. Although the materials are available, most material vendors are not prepared and knowledgeable enough to sell fire-rated assemblies. This impacts the designers and contractors who reach out to the material vendor about certain fire-rated materials. The availability of fire-rated materials impacts designers and contractor's ability to easily incorporate these materials and to comply with *NFPA 101.* Even though fire-rated materials are available, we conclude that many professionals in the country do not understand the use of fire-rated materials and do not know how easily accessible fire-rated materials are. This is indicative of the lack of NFPA knowledge and the use of fire-rated systems in the country.

Observed Deficiencies of NFPA Code Compliance

Many of the buildings in Costa Rica have noticeable deficiencies in the NFPA codes and standards. Many buildings we visited had deficiencies in both the active and passive system.

Figure 2. Contradictory exit signs, neither in accordance with NFPA 101 regulation.

Figure 3. Fire extinguisher covered by plant, inhibiting accessibility

There were many examples of insufficient passive fire protection system in buildings, including signage, means of egress and material selection. There were insufficient parts of the active fire protection system as well, including fire extinguishers, sprinklers, and emergency protocols. Buildings were more compliant with the active system than the passive system. These inadequate systems are indicative of the lack of knowledge of *NFPA 101* throughout the country of Costa Rica.

Recommendations

1. **The CFIA should publicize information on budget analyses of fire protection, which prove that fire protection systems are not a major cost burden.**

We recommend that the CFIA, and the Colegio de Arquitectos use graphs and visuals we have developed to help promote this information. By promoting these graphics, visuals, and

knowledge we anticipate that professionals will no longer concerned about the increase in cost if proper fire protection measures are implemented.

2. **The Bomberos must respect the purpose of the Explanatory Manual and eliminate the goal of establishing their manual as national code.**

We recommend the Bomberos clarify that their manual is an explanatory guide that establishes basic requirements for reducing the risk of fire in buildings. We also recommend that the Bomberos eliminate the goal of establishing their manual as national code. The Bomberos lack the man power and knowledge to achieve this. The Bomberos should rely on using the NFPA codes and standards in their reviews and inspections to ensure it is the national standard.

3. **The CFIA, CIEMI, and especially CACR should promote NFPA courses, seminars and workshops within the country, encourage their members to attend them and apply their knowledge, and work with the NFPA to ensure that courses are easily accessible.**

The CIEMI (College of Electrical, Mechanical and Industrial Engineers) and CACR (Costa Rican Association of Architects) need to promote the NFPA courses offered by the NFPA or the CFIA. Professionals should be encouraged to take advantage of the many resources available to them for learning the NFPA code

4. **The Ministry of Health and Bomberos should improve the inspection process, clarify the order of authority within the building industry, and employ more certified professionals to ensure that buildings are complying with NFPA codes.**

The Ministry of Health needs to improve and clarify the inspection process of buildings in Costa Rica. The Ministry should take more responsibility in overseeing compliance of *NFPA 101* within buildings. Additionally, we recommend the Ministry of health should employ more fire protection engineers to ensure buildings comply with NFPA codes.

Authorship Page

Abstract		All
Executive Summary		All
1.0	Introduction	Emily Andrews
2.0	Background	
2.0.1	Background Introduction	Emily Andrews
2.1	The National Fire Protection Association	
2.1.1	History and Structure	Ben Rickson
2.1.2	World Influence	Ben Rickson
2.1.3	Fires that Influenced Code Development	Ben Rickson
2.2	Colegio Federado de Ingenieros y De Arquitectos de Costa Rica	
2.2.1	History and Structure	Emily Andrews
2.2.2	Life Safety Committee	Emily Andrews Julian Nyland
2.3	Fire Protection	
2.3.1	Importance of NFPA Codes and Standards	Nick Ostrowski
2.3.2	Impact of NFPA Codes and Standards	Nick Ostrowski
2.3.3	*NFPA 1 Fire Code*	Nick Ostrowski
2.3.4	*NFPA 101 Life Safety Code*	Julian Nyland
2.3.5	Types of Fire Protection Systems within NFPA Codes and Standards	Julian Nyland
2.3.6	Code Enforcement	Julian Nyland
2.4	International NFPA Chapters	
2.4.1	Latin American Countries	Ben Rickson
2.4.2	The United States of America	Nick Ostrowski
2.5	NFPA Codes and Regulations in Costa Rica	
2.5.1	Fire Safety in Costa Rica	Nick Ostrowski
2.5.2	Common Causes of Building Fires in Costa Rica	Emily Andrews
2.5.3	Major Building Fires in Costa Rica	Emily Andrews
2.5.4	Code Enforcement in Costa Rica	Julian Nyland
2.5.5	Fire-Rated Materials in Costa Rica	Nick Ostrowski Emily Andrews
2.5.6	Contrasting Seismic Codes to NFPA Codes in Costa Rica	Nick Ostrowski Emily Andrews
3.0	Methodology	
3.0.1	Methodology Introduction	Emily Andrews
3.1	Understanding Fire Code Application, Infrastructure and Code Enforcement	Julian Nyland
3.1.1	Researching	Julian Nyland

TABLE OF CONTENTS

List of Figures

Commonly Used Acronyms

APC – Administrador de Proyectos de Construccion

CACR – Colegio de Arquitectos de Costa Rica (Architects)

CAP- Constancia de Actualizacion Profesional

CIC - Colegio de Ingenieros Civiles de Costa Rica (Civil Engineers)

CIEMI - Colegio de Ingenieros Electricistas, Mecánicos e Industriales

CITEC - Colegio Ingenieros Tecnologos

CITCR - Colegio de Ingenieros Topografos de Costa Rica

CFIA - Colegio Federado de Ingenieros y Arquitectos

NEC - National Electrical Code

NFPA - National Fire Protection Association

USA - United States of America

USG - United States Gypsum

UVIE - Unit of verification of electrical installation

WPI - Worcester Polytechnic Institute

1.0 INTRODUCTION

Architects and engineers all over the world design buildings according to various mandated codes that address Indoor Air Quality, Seismic Protection, Fire Protection, and many other issues that can impact building occupants. These codes and standards have been adopted internationally to protect building stakeholders as well as building occupants from physical and financial harm. While many countries have accomplished instituting effective construction standards to protect inhabitants, not all countries are at the same level of safety. Over the past several decades, Costa Rica had been trying to improve building codes to protect their citizens in the event of an emergency. Costa Rican legislators have issued various construction standards to protect occupants in the event of emergencies such as earthquakes, fires, floods, and terrorism. In 2005, Costa Rica adopted the National Fire Protection Association (NFPA) codes and standards after receiving public pressure to improve fire safety due to several devastating fires that occurred in Costa Rica. Professionals in Costa Rica believe that these NFPA codes are too expensive to implement and are not well suited to the nation. Therefore, many of the engineers and architects in Costa Rica do not follow the NFPA codes as rigorously as they should, leaving Costa Rican infrastructure and its citizens vulnerable to fire.

The Colegio Federado de Ingenieros y de Arquitectos de Costa Rica (CFIA) is the professional association of engineers and architects in Costa Rica. Within the CFIA is the Life Safety Committee, which is tasked with the implementation and promotion of the NFPA codes. The Life Safety Committee wanted us to research how economically and socially feasible the NFPA codes are for Costa Rican building professionals. Along with economic and social feasibility, our sponsor wanted us to research the overall impacts for the designers and contractors who are incorporating these codes into their design. We will assist in this goal by analyzing construction budgets of similar projects with fire protection measures in accordance with NFPA codes to determine the cost per square meter increase that implementing fire protection measures causes. We will also be interviewing engineers, architects, developers and material vendors to get their professional opinions on NFPA codes and what issues they see in abiding by the code. Additionally, we will research potential incentives to help motivate engineers, architects, building owners and developers to follow the NFPA codes with more commitment. By providing evidence that the NFPA codes are not a financial burden and fully capable of saving people from injury or death, we hope that this will help convince the engineers and architects in Costa Rica that following the NFPA codes is a viable and realistic way for them

to ensure protection of people and buildings, without seriously raising the general cost of construction.

2.0 Background

2.0.1 Background Introduction

In this chapter, we will discuss the history of the National Fire Protection Association and the Colegio Federado de Ingenieros y de Arquitectos de Costa Rica and an overview of their current works, the importance and impact of NFPA codes on buildings and building occupants, what these codes are, how the codes have been adopted and monitored in other countries, and the steps Costa Rica has taken to implement its own NFPA code adherence.

2.1 The National Fire Protection Association

2.1.1 History and Structure

The National Fire Protection Association (NFPA) was formed in 1896 by a small group of professionals in Boston, Massachusetts. At this time, sprinkler systems were a new design concept but did not have any installation standards. This lack of regulation led to the design of 9 different standard sized piping and sprinkler head spacings. The main goal of these professionals was to create a standard for the uniform installation of sprinkler systems. They believe the discrepancies from system to system would compromise the reliability of the sprinkler systems. The group came together and created the NFPA's first code, NFPA 13, *Standard for the Installation of Sprinkler Systems.* For more than 100 years, the NFPA has been developing and updating codes and standards encompassing all areas of fire safety. Countries all over the world are adopting these codes and standards to improve their fire safety (NFPA, 2018).

The National Fire Protection Association is a global self-funded nonprofit membership organization located in Quincy, Massachusetts. Jim Pauley is the President and Chief Executive Officer of the organization. He also serves as the Chairman of the Board of the NFPA Research Foundation. In addition, the NFPA has a 13-person committee on their Standards Council. These individuals oversee the Association's codes and standards of development activities. The committee administers the rules and regulations, acting as an appeal body. The council administers around 250 technical committees and works on over 300 documents of importance to fire protection. The organization has over 50,000 individuals around the world (NFPA, 2018).

2.1.2 World Influence

The NFPA is an international organization being adopted by nations all over the world. The organization has international offices covering the Asia/Pacific Region, Europe, and Latin America. They are trying to advance the use and adoption of NFPA codes and standards throughout these territories. The International staff works with the national and local governments to develop education programs on fire protection and safety. The NFPA also offers their codes translated into many different languages. They maintain a large presence in Latin America with many different chapters. They have created NFPA chapters in countries including Argentina, Colombia, Dominican Republic, Mexico, Puerto Rico, and Venezuela. The primary purpose of these chapters is to support the international initiative of the NFPA, by supporting foreign nations that are members of the organization. All this influence in Latin America allowed the NFPA to develop a training seminar in Spanish, and the creation of the *NFPA Journal Latinoamericano* ® (NFPA, 2018).

2.1.3 Fires that Influenced Code Development

The NFPA is constantly learning about how to update and create new codes and standards through real world incidents. There were a few key incidents in the United States that led to the adoption of new codes and standards. An example of this was the Triangle Shirtwaist fire of March 25, 1911. This fire led to the creation of the NFPA's Committee on Life Safety, which then led to its own code, NFPA 101, *Life Safety Code*. The Triangle Shirtwaist company was in the Asch Building in New York City's Washington Square. The company had over 500 employees who worked 6 days a week in cramped dirty working quarters. The building had 10 stories with wood floors and wood window frames and had only two staircases per floor while it was required to have three. The doors were constantly locked, which is also against code in an industrial setting. This factory was constantly unsafe and did not adhere to many of the codes and standards. The fire started in a pile of rags that hadn't been attended to in months. Their fire protocol was very bad, and many people weren't informed that the building was on fire until it was too late. Unfortunately, 147 people died in this accident due to negligence and the multiple violations described above. This incident led to the formation of the Safety to Life Committee. Their first act of business included a special section on egress, a statement that sprinklers can save lives and preliminary specifications for exterior fire escapes. Ever since the creation of the committee, they have been focusing on establishing proper safeguards against the loss of life and property by fire (NFPA, 2018). At that time in New York, the Asch Building was not the only

facility that was not up to code. There was an investigation on the condition of 1243 shops and it was reported 99% were deficient in safety, so this accident seemed almost inevitable.

The Triangle Shirtwaist factory is not the only example of serious incidents causing code changes. There was the Coconut Grove Fire and the Winecoff Hotel Fires, which are two additional examples of tragic fires influencing the refinement of fire protection codes. The Coconut Grove Fire occurred at the single-story nightclub in Boston, Massachusetts which did not have an adequate number of exits, costing 492 people their lives. There was an immediate change to the *Building Exit Code* directly resulting from the Coconut Grove Fire. The Winecoff Hotel Fires influenced change in codes for interior finishes. It now prevents the use of interior finishes that have a higher combustibility than wood. This was later added to the *Building Exit Code* (NFPA, 2018). Unfortunately, many advances in NFPA codes result from the aftermath of tragic incidents, with the goal of preventing such disasters from happening again in the future.

2.2 Colegio Federado de Ingenieros y de Arquitectos de Costa Rica

2.2.1 History and Structure

The Colegio Federado de Ingenieros y de Arquitectos de Costa Rica (CFIA) was founded on July 3, 1903 under the name Facultad Tecnica de La Republica by an Executive Order signed by the President of Costa Rica at the time, Esquivel Ibarra. Its first general meeting, held in the weeks following its foundation, was attended by 26 engineering professionals, and set eight commissions with various focuses. The main goal of the CFIA is to promote the progress of engineering and architecture. The mission of the CFIA is to “Ensure the excellence and propriety of our members for an efficient, responsible and interdisciplinary practice of engineering and architecture to contribute to the country’s safety and sustainable progress” (CFIA.org, 2018). This dedicated group of individuals motivates engineering and architecture progress in Costa Rica and are responsible for overseeing the permit process of many of its buildings. It has evolved over the years into a widely respected organization at the forefront of engineering in Costa Rica.

Today the CFIA is made up of five sub-colleges, seen in Figure 4, each with a separate demographic of engineering, including architects, civil engineers, mechanical and electrical engineers, and topographic engineers. These groups provide more specific support and direction for the general members, as well as professional development opportunities and career support. The CFIA places emphasis on teaching the importance of ethical and competent

Figure 4: Five Sub-colleges within the CFIA in Costa Rica

engineering practices (Zeledon, 2018). Through deploying innovative changes to Costa Rican engineering standards and placing emphasis on education of engineering practices and ethics, the CFIA has become a valuable resource for Costa Rican engineering professionals.

2.2.2 Life Safety Committee

Within the CFIA exists a Committee on Life Safety. This committee consists of architects and engineers from each representative college in Costa Rica, as shown in Figure 1 above. They have been working within the CFIA for 15 years. This committee specifically proposed the project to us as they directly work with all matters regarding *NFPA 101 Life Safety Code*. They use *NFPA 101* to design the passive and active system of buildings and to ensure life safety for the people of Costa Rica.

Figure 5. Hospital Cima San Jose, designed by Heriel S.A. (medicaltourismcostarica.com, 2019)

Working with us from this Life Safety Committee is Arq. Hernán A. Hernández. Mr. Hernández is the coordinator of the committee and the principal architect and owner of Heriel S.A., his own architecture and engineering firm. He founded Heriel S.A. 40 years ago with two civil engineers, focusing on the design of commercial buildings in Costa Rica. Mr. Hernández is a member of the CFIA and works closely with the CFIA to develop and institute best practices in life safety. He has designed many buildings such as the Hospital Cima San José, various fast food chains, various distribution centers, office buildings including some of the National

Insurance Institute (INS), school buildings and a laboratory building for the Universidad de Costa Rica. Mr. Hernández is also a certified NFPA instructor and works closely with NFPA codes when designing and inspecting buildings. He is an invaluable resource due to his experience and professional connections, as well as his passion to improve building safety in Costa Rica.

2.3 Fire Protection

2.3.1 Importance of NFPA Codes and Standards

Throughout history, a variety of structures have been burned down or nearly destroyed due to fire. There was a prominent need in society to incorporate a set of standards for owners of buildings and structures to adhere to to prevent major losses of infrastructure and lives. Occupants of buildings needed to know the safety measures to take if any emergency occurred involving fire. Legislators, fire department chiefs, and designers of structures decided to implement a set of codes that would increase the safety of the buildings and the occupants to complement the already-enforced building codes. These codes are defined as “a set of standards established and enforced by the government for fire prevention and safety in case of fire” (Encyclopedia.com, 2014). These codes in buildings can call for fire escapes, proper spacing with ceiling water sprinklers for fire suppression, and even portable fire extinguishers. Following these codes is of utmost importance to ensure that the least damage will be done to the structure, building occupants or even prevent the event altogether.

Every year, people of all ages are critically wounded or killed from fire-related disasters. These fires can range from simple house fires to large-scaled building fires that get out of control. For example, on average 7 people die every day from house fires in the US (NFPA, 2013) and in 2017, 3,500 people died from house fires (NFPA, 2019). Domestic fire deaths in which no smoke alarms were installed or in which smoke alarms were present but did not operate, accounted for 60 percent of all home fire deaths (NFPA 2013).

The NFPA is charged with developing a list of all codes that should be followed and emphasizing the importance of these codes through information on their website. The NFPA has around 300 codes and standards designed to minimize the risk and effects of fire by establishing criteria for building, processing, design and other activities in the United States, as well as many other countries (Fox Valley Fire, 2013). These codes are made by 200 technical code and standard committees that are made up of 6,000 experts in the particular field, who ensure that all codes are updated and constantly tested for their effectiveness. The importance of NFPA codes generally revolves around the overall safety for buildings and the occupants in

those buildings. These codes were put in place to ensure that every building (pre-existing or new) will have the equipment and instructions of what to do if a fire ever developed.

2.3.2 Impact of NFPA Codes and Standards

Incorporating NFPA codes into buildings has different impacts to different audiences. Owners of buildings must be aware and up-to-date with the NFPA codes in their buildings. In most cases, owners will be called upon to have regular inspections by local authorities. In these inspections, the fire safety officer will check things such as usable fire exits, proper exit signage, functional fire extinguishers in accessible places, and the proper storage and handling of flammable materials (Encyclopedia.com, 2018). Inspections will impact owners because depending on the legislation, the result could be a notice of required action or a closing of the building until it can be put into compliance with the NFPA codes. Compliance with the NFPA codes could even urge insurance companies and the government to give incentives to up-to-date buildings. One challenge to building owners, though, is that already built buildings can result in problems with the NFPA code compliance. In some cases, buildings that were already built before certain codes were adopted will not be in compliance with these updated codes. Making such changes to the buildings to bring them into compliance with the NFPA codes would cost a large amount of money from the owners to make their building safe.

Additionally, NFPA codes also have an impact on occupants of the buildings. Occupants need to be aware of their surroundings for any potential hazards in the buildings they occupy. Potential fire hazards include unattended flames in the kitchen, faulty electrical systems, smoking (cigarettes, cigars, etc.), exceeding maximum capacity in buildings, gas appliances, installation of gas systems, welding work, and many more. Also, NFPA codes require certain equipment in and around buildings. The equipment could include portable fire extinguishers, smoke detectors, exit signs, and even fire escapes in some circumstances (Encyclopedia.com, 2018). To ensure that the building occupants know what they are doing in an event of emergency, some building owners include fire or emergency drills into their safety plan. The drills give the building occupants a step-by-step plan to follow to evacuate the building. In some cases, especially in industrial sites, there may be a trained fire fighting force made up of employees called a fire brigade (Encyclopedia.com, 2018). Ultimately, owners that develop buildings that comply with NFPA codes provide their occupants with a sense of safety in case an emergency does occur.

2.3.3 *NFPA 1 Fire Code*

In order to understand the technical nomenclature that is used in the fire prevention field, we conducted research, which led to an overview of the *NFPA 1 Fire Code*. The purpose of *NFPA 1* is “to prescribe minimum requirements necessary to establish a reasonable level of fire and life safety and property protection from the hazards created by fire, explosion, and dangerous conditions” (NFPA, 2005, p. 7). Due to these necessities, *NFPA 1* includes many regulations on the active system. The code is meant to be applied to all buildings, which includes existing and new structures in the design stages. *NFPA 1* permits certain conditions that ensure that the building will be safe from hazardous events such as fire. These conditions include things such as inspections of buildings and systems, reviews of design and construction plans, access requirements for fire department information, and the testing and design of fire protection systems (NFPA, 2005, p.6-7). The code also includes the installment steps of instructions for the public in case of emergency, and fire and life safety education for the public and employees available. The code also has information on the fire safety of special events such as correct amount of egress routes and fire suppression systems in haunted houses, amusement parks, exhibits, and outdoor events (NFPA, 2005, p.7). In some cases, there are also conflicts with the code in certain countries around the world with other local codes that suit local needs more efficiently. When this conflict occurs and the country had adopted NFPA regulations, the NFPA code will overrule a local code, and any building following the local code would fail an inspection. This code is in relation with *NFPA 101 Life Safety Code* where each code ensures that the building is safe for occupancy and are constantly being updated for the betterment of safety.

2.3.4 *NFPA 101 Life Safety Code*

NFPA 101 Life Safety Code, also known in Costa Rica as *El Codigo de Seguridad Humana 101*, focuses on life safety and the passive system of a building. Passive fire protection is the fire control of systems that are built into the structure of the building and do not require human or automatic control, including the structure and materials used in the building. (Buchanan, 2017). In order to better understand *NFPA 101* code, we interviewed Mr. Hernández, who is a trained NFPA instructor. *NFPA 101* on Life Safety primarily deals with designing the structure of the building and designing for NFPA approved materials for construction. Mr. Hernández mainly deals with this code as an architect, using the code to design the structure of the building. When using the code, it is important to design for heat, smoke, gas and fire (Hernández, 2019). Stated in *NFPA 101*, means of egress are ways for

occupants to escape a building during a fire and this element is key in life safety. Another key element of the code requires that all materials near the egress routes are resistant to fire and won't produce too much smoke. According to Mr. Hernández, the main purpose of the *NFPA 101* is to protect lives, not to protect the building. The code was designed and created to prevent and resist fire for a certain amount of time in order for occupants to escape. It is broken down into smaller chapters, explicitly explaining each type of fire requirement. Chapters 1-3 are introductions and definitions about the code. Chapter 4 calls for at least 2 means of egress in the building. Chapter 6 is comprised of charts that describes how long certain materials need to resist fire. Chapter 7 explains means of egress and compartmentalizing buildings. Chapter 8 also explains compartments, along with fire doors and firewalls. Chapter 9 briefly explains active fire protection systems, including emergency protocols. Chapter 10 clarifies how interior materials need to be fire resistant and Chapter 11 covers special structures and high-rise buildings. All these elements described above are some examples of how the *NFPA 101* maintains life safety in buildings.

2.3.5 Types of Fire Protection Systems within NFPA Codes and Standards

There are many types of fire protection systems within NFPA codes and standards that can be utilized in fire protection. Analyzing different types of fire protection systems helps determine the most effective fire protection plan. *NFPA 1 Fire Code* is the basis for all fire protection practices and it is a national code. It consists of many different types of fire protection systems and standards that are explained and tested by the NFPA.

The safety of people in the case of a life-threatening fire depends on many factors including performance-based structural design and construction, the active fire protection system, and the passive fire protection system. Many countries have recently adopted performance-based fire codes, as opposed to prescriptive fire codes. In the book, *Structural Design for Fire Safety*, it states that in general, prescriptive fire codes are rules for the construction of a building, whereas performance-based fire codes state how a building will perform under certain conditions (Buchanan, 2017, p. 2). For prescriptive fire codes, designers are limited to established rules and must follow certain regulations. Performance-based codes allow designers to create innovative solutions for fire protection as long as the codes meet required safety and performance.

Structural fire engineering has made many advancements and continual improvements to structural fire codes. Structural fire engineering focuses on fire resistance of buildings and how the structure of the building will react in fire situations. Material and support strength are

tested to determine the structural strength of a building and designers use this testing to “use innovative methods and materials to provide structural fire safety at reasonable cost”, as stated in *Structural Design for Fire Safety* (Buchanan, 2017, p. 5). Structural based fire codes are very important, as buildings have collapsed during fire conditions. An example of a high rise building that didn’t collapse during fire was the Grenfell Tower in London, which stood ablaze for more than 24 hours, but at the same time killed at least 79 people (Palin, 2017). The Grenfell Tower was built in the early 1970s at a time when strict new building regulations were put in place to protect high rise structures from collapsing due to a blast or major fire (Palin, 2017). These regulations were introduced because of a gas explosion at the Ronan Point high-rise building in East London, which partly collapsed in 1968 (Ronan Point, n.d.). The partial collapse of the Ronan Point building had heavy implications on the future safety of the Grenfell tower, and other high-rise buildings around the world. The Grenfell Tower standing tall amongst a blazing fire was a direct result of the UK improving structural safety regulations. In 2009-2013, U.S. fire departments responded to an estimated average of 14,500 reported structure fires in high-rise buildings per year. These fires caused an average of 40 civilian deaths, 520 civilian injuries, and $154 million in direct property damage per year (Ahrens, 2016). An understanding of how the structure of a building will react in extreme temperature conditions is critical in the implementation and enforcement of NFPA codes.

Another type of fire protection system that can be utilized in buildings is active fire protection. Active fire protection or active control is the control of a fire by action of a person or automated device or system (Buchanan, 2017). Automatic sprinklers are the most effective type of active fire protection. An automatic sprinkler system will release water over a small area if it senses an increase in temperature. If the increased temperatures continue to spread across the building, multiple sprinklers will activate. Other examples include a control system to remove smoke and toxic products from the building and the use of fire extinguishers to put out small fires. Firefighters use active fire protection but it often takes them an extended period of time to arrive at the fire. Active fire protection is important in the early stages of a fire, while passive fire protection becomes more important as the fire grows and spreads. Passive fire protection is the fire control of systems that are built into the structure of the building and do not require human or automatic control (Buchanan, 2017). Passive fire control includes the selection of fire-rated materials used in the building. The selection of fire-resistant materials used inside the building can help prevent the fire from spreading. Fire-rated doors and walls are key aspects of the passive fire protection system. Other types of passive control include means of egress, and compartmentalizing. Compartmentalizing a building into sections helps prevent the spread of

smoke and fire throughout the entire building (Life Safety Services, n.d.). Secured means of egress are the ways for occupants to leave a building. The use of the passive system limits damage to the building and helps occupants to escape the building in time. Hernán Hernández believes that passive fire protection is much more important for life safety of building occupants. In general, all buildings follow a combination of both passive and active fire protection to decrease the possibility of ignition, and in the case of a fire, to decreases the spread of fire and smoke, structural collapse, and to allow easy escape for occupants and firefighters.

2.3.6 Code Enforcement

Code enforcement is very important in the success of fire protection programs. There are many different aspects of NFPA code enforcement. Code enforcement is the process of ensuring compliance with all codes, ordinances, laws, and other regulations (Coffman, 2013). In reality, code enforcement is any action taken to ensure organizations are correctly following NFPA codes and standards. The codes can be enforced by legal measures with dedicated fire inspections. They can also be enforced within the organization using guidelines. In 1978, the NFPA, in a joint effort with the Urban Institute, the U.S. Fire Administration, and the National Science Foundation, released the results of the study "Fire Code Inspections and Fire Prevention: What Methods Lead To Success?" (Coffman, 2013). They conducted a study to analyze the effects of fire inspections and the result showed the benefits of using code enforcement. The study used data from 17 cities and one metropolitan county and examined fires for which the dollar loss exceeded $5,000 (Coffman, 2013). After code enforcement had been implemented for these cities, the number of fires had decreased through the work of the fire safety programs. Code enforcement staffing models include personnel who are trained professionals in the field. This staff includes full-time uniformed fire inspectors, and part-time firefighters. After an established fire protection program has been implemented, it is the job of the organization to comply with these rules and it is the job of the inspection team to continually ensure compliance and safety (Coffman, 2013).

2.4 International NFPA Chapters

2.4.1 Latin American Countries

The NFPA has influence all through Latin America. They have 6 chapters in Latin American nations, which include Argentina, Columbia, the Dominican Republic, Mexico, Puerto Rico and Venezuela. Although these chapters exist in Latin America the implication and the utilization of the NFPA codes are very poor and not strictly enforced. The NFPA offers training

seminars throughout these regions in Spanish. Additionally, the NFPA's international operations publishes *the NFPA journal Latinoamericano* (NFPA, 2018). These nations have access to material from the NFPA but aren't utilizing them to their full potential. The architects and engineers aren't getting the education needed to fully understand the codes in manner where they can be successfully implemented in construction. The influence of NFPA codes in Latin America are not equally prevalent in all the nations. Looking into the NFPA training seminar calendar for the upcoming year of 2019, there are no seminars in Venezuela and Columbia. This means that anyone from these nations that are looking to use the NFPA codes and attend these seminars have to go to other nations receive this information.

2.4.2 The United States of America

The United States of America is one of the world's leaders in fire safety and enforcement. The USA is the home of the NFPA headquarters which is in Quincy, Massachusetts. Analyzing what makes the USA so successful can provide insight on the improvements that can be made in Costa Rica to their fire safety programs. There are around 8 million buildings that legally require a fire safety plan in the USA, and not having a fire safety plan for buildings that comply with the NFPA codes can result in a fine or closing of the building (Encyclopedia.com, 2018). The USA has strict inspections along with the codes that are meant to ensure compliance. The USA follows the NFPA codes and incorporates them into all their structures being built. Costa Rica could use the United States successes in fire safety to provide compelling evidence to strengthen their own abidance to NFPA codes. Architects and engineers in Costa Rica are working to develop their buildings to the NFPA standard. Fire protection engineer Eduardo Armijo agrees that the U.S. association's codes are effective in preventing and controlling fires but says a call to suddenly bring all the country's buildings up to those standards is unrealistic (Goodier, 2005). The National Insurance Institute (INS), however, argues that this would not be a sudden move and the standards have been the same since 1994 (Goodier, 2005). In the effort to improve life safety in Costa Rica, building professionals will continue to work on emulating the successes of the NFPA standard in the United States of America.

2.5 NFPA Codes and Regulation in Costa Rica

2.5.1 Fire Safety in Costa Rica

To ensure a safe environment in buildings, regular inspections of fire prevention tactics are critical. In Costa Rica, fire safety inspectors from the National Insurance Institute (INS) rarely visit buildings to conduct check-ups. The reason for this is because the fire safety department is understaffed (Goodier, 2005). The shortage of staff means that they cannot inspect every building, resulting in many unsafe buildings that are not up-to-date with the NFPA codes. In fact, the staff from INS had inspected only 227 buildings between the years 1994-2005 (Goodier, 2005). A local fire protection engineer, Eduardo Armijo, suggests that the INS, which holds a monopoly on insurance in Costa Rica, should complete more post-construction check-ups and keep building maintenance workers on their toes (Goodier, 2005). It was found through those few inspections that many of the buildings in Costa Rica do not comply with the NFPA codes, including some famous landmarks such as the Central Bank and ironically, the INS building itself. One of the reasons that many of these buildings are not up to code is because construction professionals say that the buildings would have to be built from scratch in order to comply (Goodier, 2005). Randall Murillo, the construction chamber's executive director, states that "even in advanced countries, the norms for new buildings differ from those for existing buildings. We aren't against safety measures in buildings; we want them to be stricter. We are saying it is technically impossible to meet some of the conditions" (Goodier, 2005). Some of the conditions would require wider hallways, or additional exits which would be difficult to accomplish without completely rebuilding. For this reason, there is a public opinion that believes implementing NFPA codes would be too expensive.

2.5.2 Common Causes of Building Fires in Costa Rica

There are many causes of fire that need to be considered when developing NFPA codes. The most common causes of building fires in Costa Rica are electrical equipment and cooking equipment. According to the Bomberos, Costa Rica's National Corps of firefighters, places of high poverty are the most susceptible to fire due to inadequate electrical wiring. Flammable oils, as well as hot gas elements found in many residential and commercial buildings with kitchens can cause major fires (Unifourfire.com, 2017). Another common cause of building fires is electrical and lighting equipment. Faulty wiring, loose connections, electrical imbalances and old wiring can cause electrical shorts which lead to building fires. According to Ing. Hector Chaves, the head of the Bomberos de Costa Rica, nearly 1,000 people every year are left

homeless due to electrical fires (insidecostarica.com, 2012). Many buildings are built without consulting an electrical engineer, which also leads to improperly balanced and poorly designed electrical systems. Costa Rica has plenty of electrical engineers that could be utilized for designing building wiring, but they are not commonly used in Costa Rica (Hernandez, 2019). According to Hernan Hernandez, Costa Rica adopted the National Electrical Code (NEC) around 20 years ago. In 2012, Costa Rica created a new decree, which updated the use of the National Electrical Code. This new decree included five new elements, which included the UVIEs with a licensed CAP engineer required in order to inspect buildings. The NEC code reduced the number of contractors who install electrical wires without a legitimate electrical license and increased the standards of electrical wiring in buildings. This will hopefully serve to decrease electrical fires in the future (insidecostarica.com, 2012). Improving building codes and government oversight of inspection processes can decrease cooking equipment and electrical fires in buildings.

2.5.3 Major Building Fires in Costa Rica

One of the biggest motivators that propels change in NFPA codes and legislation are major building fires that cause preventable deaths due to lack of code compliance. Costa Rica has had several devastating building fires that have helped motivate change regarding NFPA codes. One of these fires was the Calderon Guardia Hospital Fire, which occurred in San Jose in 2005. Due to the building not being up to the Costa Rican Construction code which includes some NFPA conditions, there were minimal fire exits that were not protected, the hospital did

Figure 6. Black Star Line Fire (ticotimes.com, 2016)

Figure 7. Calderon Guardia Hospital (CRHoy.com, 2019)

not have fire escapes, emergency evacuation protocol or emergency lighting (NBC News, 2005). Additionally, the fire alarm system did not sound properly due to lack of maintenance. This fire caused the loss of 19 lives, as well as rendering 522 hospital beds unusable in one of

Costa Rica's largest and most prominent hospitals (PAHO.org, 2005). This fire motivated the Benemerito Cuerpo de Bomberos de Costa Rica to publish a decree, making NFPA codes required by law, due to pressure to avoid a similar tragedy (Ticotimes.com, 2005). Another fire which occurred in the Limon province destroyed 75% of the historic Black Star Line building, said to be the most representative example of Caribbean architecture in the Limon province (Tico Times, 2016). This building was built out of zinc and wood in 1922, and was renovated in 2000, and named an architectural heritage site. While millions had been invested in restoring and preserving the building, little concern was shown regarding the safety of the building. The building had no fire alarms, nor access for disabled people, and was unable to obtain an insurance policy due to lack of code adherence. These fires have drawn public criticism and put the government under pressure to increase building safety.

2.5.4 Code Enforcement in Costa Rica

NFPA codes in Costa Rica is enforced differently than in the United States. In Costa Rica, the Bomberos and the Ministry of Health work together to review NFPA codes and standards compliance in construction. It starts with the professionals, engineers and architects, who submit construction documents through a digital platform called the Administration of Construction Projects (APC), which was created by the CFIA. The CFIA then assigns the project a number and becomes available to Bomberos, the Ministry of Health and some of the local municipalities. The Bomberos act as consultants to the Ministry of Health, review construction documents and performing on-site inspections, and generate reports regarding their findings. The Ministry of Health and Municipal governments hold the power to issue operational and occupancy licenses, based on the Bomberos' observations regarding new construction. The Ministry of Health must inspect buildings every 3-5 years in order to give occupancy licenses. They also cannot issue licenses if the building is found non-compliant. The Bomberos perform regular inspections every 3 years to maintain building compliance. The Secretary of Education is also in charge of reviewing educational buildings and life safety within the buildings (Hernandez, 2019). There is very little code enforcement for housing in Costa Rica, especially lower income housing. The Ministry of Transportation also plays a role in enforcing NFPA codes for public transportation routes. NFPA Codes are not strictly enforced in Costa Rica, which leads to insufficient fire protection systems in buildings.

2.5.5 Fire-Rated Materials in Costa Rica

In Costa Rica, fire-rated materials are readily accessible for builders to obtain. Even though the fire rated materials are available, they are not consistently purchased, and engineers and architects are not specifying that their building requires fire-rated materials. (Hernandez, 2019). Some examples of fire-rated materials that are available are wall insulation, ceilings, walls, and doors. For materials to be considered fire-rated, and in compliance with NFPA 101, they must be tested by a third-party laboratory and labelled properly if they pass the fire tests. It is for this reason that materials need to be rigorously tested for proof that they are in fact fire-rated. One example of testing that can be done with insulation is called the radiant insulation test, which is mentioned in *NFPA 285 Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components* and *NFPA 286 Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth* (Hernandez, 2019). In this test, a fire is started in a corner of a room that is covered with the insulation being tested, and scientists record their observations and temperatures of failure. They also time how long the insulation takes to ignite, as well as if it causes a flashover, which occurs when a fire spreads rapidly due to intense heat (firerescuemagazine.com, 2019).

In some cases, material vendors will have both compliant and non-compliant products. Frequently, designers and developers will choose the inferior and more universally used product for their buildings, which is generally the one that is not fire compliant because it is less expensive (Hernandez, 2019). Developers and designers do not usually emphasize the difference in product quality or NFPA code adherence between comparable products, which leads designers and developers to choose the cheaper option to specify in the construction plans. We hope that our research will assist designers and vendors to prioritize fire protection materials in their respected markets.

2.5.6 Contrasting Seismic Codes to NFPA Codes in Costa Rica

In Costa Rica, most construction codes are followed when designing new structures. Since Costa Rica is geographically located on the Ring of Fire, people in the construction industry feel it is important to adhere to the seismic codes. The “Ring of Fire” is a 25,000-mile (40,000 km) horseshoe shaped continuous series of oceanic trenches, volcanic arcs, and volcanic belt or plate movements that borders the continents of Asia, and down the Pacific coasts of North America and South America. Along this horseshoe shape, many earthquakes

result from the spontaneous plate movements. It is for this reason that Costa Rican construction incorporates seismic codes into their design carefully. According to the CFIA, they created seismic codes in the 1970's, but the latest version of the code was adopted in 2012.

There was a strong earthquake that hit Costa Rica and bordering countries in 2012. The magnitude of this quake was 7.6 out of 10, which is one of the strongest in the country's history (Farley, 2012). Even though the magnitude of the earthquake was high, there was not as much damage as the magnitude might warrant. The damage included some blocked roadways, some structural damage, and collapsed houses, and only one death, but from a heart attack (Farley, 2012). One reason that most buildings withstood the shakes from the ground was because most of the buildings were made for that with the seismic codes being followed.

A comparative analysis can be done in accordance with seismic codes and NFPA codes and the results of adherence to them. Costa Rica's ability to adhere adequately to the seismic codes it has adopted suggests that it can also adhere to the NFPA codes. As shown above, following seismic codes can limit damage and the loss of life. Adopting NFPA codes in other countries has shown signs of improving building safety and decreasing loss of life from building fires. In the subsequent chapters, we hope to prove that this is also the case for Costa Rica.

3. Methodology

Our project was aimed at working with Heriel S.A. and the CFIA to analyze construction budgets and develop a cost per square meter for buildings that follow NFPA codes and buildings that do not in order to prove that following the NFPA codes aren't a financial burden. We also interviewed various industry professionals in order to understand the social and economic implications of following the NFPA codes. We achieved this goal through the following objectives:

1) Understand current NFPA code application, infrastructure and enforcement procedures in Costa Rica
2) Analyze construction budgets to determine the overall outstanding costs of a building that follows NFPA codes and a building that does not
3) Gauge the needs and motivations of the building architects, engineers, vendors and occupants to determine opinions and social impacts of NFPA codes
4) Provide evidence that following the NFPA codes is not a large financial burden, and justify whether or not incentives for NFPA code compliance are needed

We achieved these objectives through the following steps:

1) Objective 1: Researching and Interviews
2) Objective 2: Budget Analysis
3) Objective 3: Multiple Interviews
4) Objective 4: Data Analysis

We synthesized information from stakeholders to help determine the feasibility of implementing NFPA codes in Costa Rica to newly constructed buildings. It was important to know how stakeholders anticipate the potential impacts of following NFPA codes, and it was crucial to learn this before we make recommendations for the CFIA. Our deliverables will include a cost per square meter analysis of construction budgets and an analysis of stakeholder opinions on the matter as well as potential incentives, which we utilized to make recommendations on feasibility, implementation methods, construction cost impact and incentives to promote fire safety in Costa Rica, from which the CFIA can choose from based on their needs. We achieved the goals of the project by following the methods and data analysis techniques as outlined in the subsequent sections.

3.1 Understanding NFPA Code Application, Infrastructure and Code Enforcement

In order to achieve our goal of assessing whether NFPA codes are a significant financial burden for new buildings, our group had to understand current NFPA code application, infrastructure, and NFPA code enforcement in Costa Rica. We built a strong foundation of research prior to our arrival in Costa Rica, as expressed in our background chapter, in order to have a full understanding of what we might expect. Without extensive research and background knowledge, we could have misinterpreted NFPA code application and data analysis while in Costa Rica.

3.1.1 Researching

To better understand NFPA code application and code enforcement, we used resources through the WPI database to gather relevant and reliable information. We researched the structure of the NFPA and the codes they have implemented. We used the CFIA website to study how they structure their organization. Most of our research was conducted through the WPI library database. In order to expand our knowledge on NFPA code application and code enforcement, we used the fire protection engineering database to find articles and scholarly journals. Fire codes and the impact of infrastructure on fire codes was clearly defined in *Structural Design for Fire Safety,* 2017, a book written by Andrew H. Buchanan and Anthony Kwabena Abu.

3.1.2 Interviewing

When our team had constructed a strong background, we interviewed Professor Milosh T. Puchovsky from the WPI Fire Protection Engineering department prior to arrival in Costa Rica. We chose to interview a professor from the Fire Protection Engineering department because we knew he would be a source reliable information for our project. The department also has strong experience in the field and would have suggestions for working with NFPA codes in Costa Rica. We focused our questions mainly on NFPA code application and code enforcement in the United States. In addition, we asked about construction cost impacts and feasibility of NFPA code application in developing countries. This information helped us gain a greater understanding on the impact of NFPA codes in the United States and gave a basis for potential recommendations for the impact of NFPA codes in Costa Rica.

Once we arrived in Costa Rica, we interviewed Mr. Hernández. We worked with him directly on this project so we generated beneficial conversation through questions and discussion. He improved our knowledge on *NFPA 101 Life Safety Code.* He was able to clarify

information regarding typical infrastructure and code enforcement in Costa Rica. In addition, we conducted an interview with the Bomberos fire department to discuss their role in code enforcement. They clarified information regarding inspections and reviewing construction documents. Once we assembled strong information about NFPA code, infrastructure and code enforcement, we were able to achieve our subsequent objectives.

3.2 Analyzing Construction Budgets

To better understand of the economic impacts of NFPA code implementation, we analyzed construction budgets provided by the CFIA. These construction budgets included all material and labor costs. We were given a budget for three Costa Rican buildings, one that is NFPA code compliant, and two that are not. For the NFPA code compliant building, we looked at the material costs and labor costs and calculated the percentage of the total construction budget is dedicated to purchasing and installing fire protection materials and systems.

For the non-compliant buildings, we developed a proposal that included all necessary fire protection materials and labor that are required to make the building NFPA code compliant. From this proposal, we determined percentage of the total construction budget that was dedicated to fire protection materials and installation costs. While we included additional measures to ensure the building complies, there are some small costs that we were unable to quantify that are needed for NFPA Compliance. The purpose of these metrics is to obtain actual numbers that prove that fire protection measures do not cause a significant construction cost increase.

After the completion of our data analysis of construction budgets, we began to compare the cost per square meter metrics that were obtained. Our sponsor correspondent, Hernan, predicted that the inclusion of fire protection materials would only increase the total construction budget by 3%, and we hoped that our construction budget analysis would prove that he was correct. Some issues we encountered in this step include difficulty obtaining budgets from the groups the CFIA had contacted on our behalf, as well as difficulty determining which materials were fire-rated from these budgets, as our knowledge of construction materials is limited at this time.

3.3 Gauging the Needs and Motivations of Stakeholders

A stakeholder, simply put, is one who has something at stake in a certain situation. Our major stakeholders in our project would include the engineers and architects of various organizations, the CFIA, vendors of materials and owners of buildings that we were able to

analyze. We focused on collecting critical information through simple conversations and interviews. These interactions and data collecting methods encouraged us to understand the perceptions of the NFPA codes as seen by people who are familiar with the subject.

In a meeting with our sponsor correspondent, Mr. Hernández, we obtained valuable information about the stakeholders. Mr. Hernández suggested that we add a few more people to that group such as developers and to have more of a focus on architects. Architects are responsible for the design of the building and life safety of occupants and they work more directly with the building owners. We were able to go through our lists of questions for these groups, and Mr. Hernández assured us that the questions, and subsequent responses would collect the information we are searching for.

3.3.1 Interviewing the Stakeholders

We found that the best way to find the social effects that fire and life safety code compliance has on people was to give semi-standardized interviews to engineers, architects, developers, construction specialists, and material distributors. Since we had different people who had different areas of expertise, we needed to make sure that we were prepared with separate sets of questions that captured the information we needed. Semi-standardized interviews are generally a set of open-ended, systematic questions that allowed us, as the interviewers, to delve into certain subjects and veer off the script for a bit if we found it beneficial (Berg, 2012, p. 112). This interviewing style worked best for us in San Jose because it allowed us to speak freely with our interviewees without making it seem like we had a script to follow, which made the conversation feel more natural for the interviewee.

Interviews included questions about personal views of the importance of fire and life safety codes and whether these codes are believed to be cost effective for implementing them in the early stages of construction, with some questions about code enforcement. Our questions varied with each expert to shift the conversation to their area of study or work. From these questions, we were able to learn the motivations and needs that inspired the fire and life safety codes related to our project in San Jose. We began the interviews with the architects, life safety engineers, and electrical engineers who saw the need to constantly improve fire and life safety codes in buildings for the betterment of its occupants' safety. Some questions we asked the architects and engineers were mainly about *NFPA 101 Life Safety Code* and *NFPA 1 Fire Code*. and how familiar they were with it. Particularly with fire prevention specialists, we were able to ask questions about their expertise with inspecting buildings and what problems they saw. We

were also able to get some information on why they thought some builders did not follow the fire and life safety codes.

There was a need for information from the construction specialists on their thoughts concerning *NFPA Code 1* and *NFPA Code 101* and the reasons they perceived for negligence relating to the codes. We thought that if we went to the people that had a direct role in building the structure every day, we could collect the best information for our report. The interview provided insight on the level of knowledge that the construction specialists had on fire and life safety codes.

We shifted our focus to the material vendors that had an impact on the quality of these buildings. Among the questions we had were what they thought the extra cost would be to the owners to bring their buildings into compliance with the NFPA codes, how readily accessible fire-rated materials are in Costa Rica, if they thought NFPA codes were expensive to implement, and if they encouraged architects and engineers to use their fire-rated products. Receiving information from those who would be directly affected by this project ensured the best possible results for our findings.

We also thought it was necessary to conduct an interview with a developer of a building to gauge their knowledge of their buildings' safety, to round out the information we obtained to ensure it included all relevant parties. We wanted to know if they were aware if their building included some vital equipment and instructions in case of an emergency. Additionally, we wanted to see the consistency of inspections and updates they had in their building.

3.3.2 Compiling the Evidence

Using the information from our interviews and surveys, we were able to provide evidence about the social implications that NFPA code compliance has on society. Through these interactions, we sought to answer some specific questions related to our project goals. These project goals included determining whether or not that implementation of the life safety and NFPA codes were cost efficient and determining the reasons that life safety and NFPA code compliance is so uncommon in Costa Rica.

3.4 Provide evidence that following the NFPA codes is not a large financial burden, and justify whether or not incentives for NFPA code compliance are needed

As our study progressed, there were many different types of influences when collecting evidence and data to determine whether the costs associated with NFPA code compliance were

justifiable. We then investigated whether or not monetary incentives would be effective due to the financial burden NFPA codes can have on construction. Throughout our data interpretation we are able to decide what types of incentives might be most useful and beneficial toward the implementation of NFPA fire codes in Costa Rica.

3.4.1 Interpreting Data

We collected our data from research and many different types interviews. The Interviews we conducted concerned fire protection measures, life safety code, fire code compliance and materials. Once the data were collected, we compiled the evidence into social and economic impacts on fire protection in Costa Rica. We were able to take these data and interpret them in such a way to produce a series of recommendations to help implement.

3.4.2 Incentives

Throughout our research we discovered many different types of incentives that could possibly be implemented in Costa Rica to improve fire protection in buildings. Some incentives include subsidies and tax cuts for proper fire protection practice. Our sponsor correspondent, Mr. Hernández, believes a good way to approach the costs of implementing fire rated materials is to make them tax exempt. The sales tax in Costa Rica is around 13% and the consumption tax is 1%, these taxes can significantly increase the final cost of materials (Hernández, 2019). These types of monetary incentives will have more influence on the Costa Rican building owners compared to the sole idea of increased fire safety within buildings that implement fire codes. Although the main concern should be the safety of building occupants and users. This could be achieved through the means of the reduced costs of fire rated materials.

3.4.3 Financial Impacts of NFPA Code Compliant Buildings

We conducted research on buildings that are already up to NFPA code and achieve NFPA code compliance in a cost-effective manner. We found this information through online research and personal contact with professionals in the field. The goal for learning about cost effective NFPA code compliant building is to provide the people of Costa Rica with the realistic possibility that they can increase the fire safety of their infrastructure without prohibitive costs.

From our collected interview responses, as well as analyses of construction budgets, we reviewed and synthesized the evidence we found to see if there was a definitive answer to if implementing NFPA codes is prohibitively expensive. With our extensive research into current Costa Rican NFPA codes, as well as the successful implementation of NFPA codes in other countries, we were able to form several conclusions on the feasibility of NFPA code compliance, as well as the impact on building safety that NFPA code compliance would have in Costa Rica

3.5 Methodology Conclusion

In conclusion, following the steps we discussed in our methodology chapter guided our team to achieve the goal of proving that following the NFPA codes should not be a prohibitive financial burden by analyzing construction budgets and developing a percent cost increase for buildings that follow NFPA codes and buildings that do not. In addition, these steps guided our team in assessing the social and economic implications of following the NFPA codes by interviewing various industry professionals.

4.0 Findings

Upon arriving to Costa Rica, we were told that we should focus primarily on the *NFPA 101 Life Safety Code*, which helped narrow our research and interview focus. While conducting interviews and walking through various buildings in Costa Rica, the questions we were hoping to answer included “How does the *NFPA 101* impact this person or place?”, “What are this person’s ideas of the *NFPA 101*?” and “How much do they actually know about the *NFPA 101*?”. Our research, interviews and budget analysis concluded with certain observations and impacts that we have outlined below. We determined that the best way to portray our findings was to find common themes from our interviews and budget analysis. This led to our 3 finding groups: knowledge; cost and availability; and observed deficiencies. A prominent issue that came up in every interview is the sincere lack of knowledge that the public and building professionals have regarding the *NFPA 101*. Additionally, looking at the budgets we were given and comparing the numbers with the professionals’ preconceived notions of how difficult and expensive implementing fire protection measure gave way to the second category, cost and availability. Finally, we observed blatant and frequent violations of NFPA codes in almost every Costa Rican building. This was an important step in our development of the project because it allowed the team to see the non-compliant examples of these buildings. We wanted to portray the diverse impacts of our findings accurately, and separated them into two subcategories, impacts on society socially and impacts on society economically.

4.1 Observed Deficiencies of NFPA Code Compliance

Traveling frequently in Costa Rica made it possible and easy to make many observations of non-compliance to *NFPA 101 Life Safety Code* in multiple buildings. We consistently found that buildings were lacking some major life safety equipment and instructions. We observed various types of active and passive fire protection equipment that was either absent, poorly located, or not in accordance with *NFPA 101*. The proof included in this section is indicative of how widespread the lack of knowledge about *NFPA 101* in throughout Costa Rica and how it affects everyone, not just the professionals. This section is not intended to target various locations for their lack of fire protection, but to emphasize the consistency in deficient fire protection in the country, which is an underreported and underemphasized issue.

4.1.1 Introduction to the Active and Passive System

We visited many buildings throughout Costa Rica with many deficiencies in both the active and passive fire protection systems. Following the *NFPA 101 Life Safety Code* is crucial for the safety of occupants in buildings and finding inadequacies within the fire protection systems impedes the success of the systems. *NFPA 101* focuses mainly on the passive system and that is where we found most of the deficiencies. We found many examples of insufficient parts of the passive system in buildings, including signage, means of egress and material selection. We also found insufficient parts of the active system as well, including fire extinguishers, sprinklers, and emergency protocols. We found that buildings were more compliant with the active system than the passive system. We also obtained information regarding lack of emergency protocols and fire-rated materials through some of the interviews we conducted. In the ensuing sections, we will be examining each active or passive system deficiency in detail.

4.1.2 Signage

NFPA 101 Life Safety Code specifies only one exit sign that is in accordance with their regulations, which can only be purchased from one manufacturer, located in Greece. This sign must be visible from 30 meters away, must be lighted, and only have arrows if appropriate and pointing towards a fire exit. For this reason, we saw many exit signs that were not the correct regulation sign, that were too small and not lighted, as well as having arrows that did not point to fire exits. These signs, which were often hard to find, were placed below or above eye level, and which could not be seen from 30 meters, were spotted in restaurants, hospitals, office buildings and stores, all places that are regularly occupied. In several places, there were signs that were contradictory, covered by pipes, or said something other than “Salida”. This issue is widespread

Figure 8. Contradictory Exit signs (By Authors)

Figure 9. The only NFPA approved exit sign in Spanish (By Authors)

Figure 10. Evacuation sign with extraneous information that is difficult to read (By Authors)

throughout Costa Rica, and while it seems like it is better to have any sign rather than no sign, improperly placed signs can confuse building occupants who are trying to escape in a potential emergency, lead them to areas of the building which are not reinforced horizontal exits or can melt before all occupants are able to escape. Another major issue with signage is related to posted evacuation routes. These are supposed to be developed by the architect of the building, who provides a schematic drawing of the layout, and marks two safe, reinforced horizontal hallways to two building exits and should be posted at eye level with no other information besides exit routes. However, we saw many examples of evacuation routes that pointed to unsafe exits, were unclear in intended exit routes, faded, and which included additional unnecessary and distracting information such as the location of fire extinguishers, fire blankets and fire hoses. While this information is well intentioned, the point of fire extinguishers, fire blankets and fire hoses are to be logically located and easily accessible in case of a fire. These evacuation routes and exits signs are common throughout the country and are not in accordance with the *NFPA 101*.

4.1.3 Means of Egress

Means of egress is a focal point of *NFPA 101 Life Safety Code* and we found many means of egress in buildings that were not up to code. Mr. Hernández believes means of egress is one of the most important passive systems of a building and finding insufficient means of egress directly puts occupants at risk during fire. A means of egress is a way for occupants to escape the building, which includes doorways, fire-rated doors, corridors, and stairwells.

While visiting buildings in the country, we found that many stairwells were not up to code and were not safe enough to protect occupants during fire. In *NFPA 101*, it states that the main staircase of a building must be enclosed with fire-rated materials. While visiting a hospital in Costa Rica, we noticed that the main stairwell was open and would be very easy for fire to spread throughout the building. We also noticed many stairwells built with combustible materials. It states in *NFPA 101* that there must be at least two means of egress in a building and there are a several specifications included within the code. For example, the code requires a maximum distance of 30 meters from an occupant's seat to a main corridor. It also requires a maximum distance of 91 meters from a main corridor to a stairwell. We noticed that many stairwells were not properly placed and did not follow these specifications.

Along with stairwells, we found some corridors that were not up to code due to lack of horizontal exits within the corridors and the overall width of the corridors. Also, we noticed in some places there were combustible materials piled up in the corridors, which would increase

the spread of fire and is a fire hazard. Corridors and hallways are the main escape route for occupants and are crucial for life safety.

We also found many inadequate doorways and fire doors in many of the buildings we visited. Many of the doors used for the main means of egress were not fire-rated and not equipped to handle the spread of fire, smoke and heat. The main deficiencies we have seen with fire doors is that they are painted or missing required fire door labels. Many doorways also had poor clearance dimensions and sometimes had equipment and furniture surrounding and impeding the opening. The *NFPA 101* strongly focuses on the design of means of egress and the use of *NFPA 101* compliant doorways, corridors and stairwells. We find that these insufficient parts of the passive system do not adequately improve life safety of occupants.

4.1.4 Meeting Points and Safety Points

Another major and consistent concern that was seen all around Costa Rica is signs that say “Punto de Reunion,” or “Meeting Point.” The most pressing issue concerning these signs is

Figure 11. Meeting Point Sign in front of building (Hernandez, 2019)

that they are encouraged by the Bomberos during inspections but are not required by the *NFPA 101 Life Safety Code*. These meeting point signs were frequently found to be less than 30 feet from the building or in the way of the intended fire lane. One was even observed in the courtyard of a building complex, surrounded by other buildings and not near any exits. These can be a significant safety issue in the event of an emergency, as people will gather too close to the building and be in the way of emergency vehicles that need to access the building. These signs were seen outside of almost every building and were poorly placed. Although these signs

are a well-intentioned precaution, they can confuse building occupants, direct them to unsafe locations and severely limit access for emergency vehicles.

4.1.5 Fire Extinguishers and Sprinkler Systems

Many new buildings in Costa Rica follow the active fire protection system protocol over the implementation of the passive system. Almost every commercial building in Costa Rica has multiple fire extinguishers. Although most of the time the extinguishers are present, there can be many problems that arise with them. Not all occupants and workers inside a building are trained to use the extinguishers in the case of an emergency, rendering them much less effective. Another problem with the fire extinguishers is that they are often covered or obstructed by other objects. Some examples we discovered were extinguishers being covered by plants or furniture, which could make it very difficult for an occupant to find the extinguishers in the case of an emergency. There were also cases where fire extinguishers were missing from their allotted boxes, causing the false advertisement of an extinguisher. It has also been seen where there are signs directing one to an extinguisher that was not there. There are also cases where the extinguishers have the wrong type of extinguishing agent for the job.

Figure 12. Missing Fire Extinguisher (By Authors)

Sprinkler systems are also a type of active system commonly implemented within buildings in Costa Rica. A lot of the time sprinklers systems are installed in building that have very little passive fire protection measures. The sprinkler system is supposed to be able to provide enough early fire suppression for occupants to be able to evacuate the building. With no passive fire protection, the fire in the building could be too great for the active sprinkler system to be effective. Another problem with sprinkler systems is they are not implemented in every commercial establishment. We saw many examples in commercial buildings like warehouses that have no form of active sprinkler system. There are even instances where the Bomberos are requiring a sprinkler system in structures that don't need a system according to the NFPA. We visited an automated parking garage under construction where the developers were required to implement a sprinklers in accordance instructions from the Bomberos, but was not actually needed in following with *NFPA 13: Standard for the Installation of Sprinkler Systems*. The

structure is a unique concept, there being only a few in world. This is leading the NFPA to create a regulation and study for a structure of this nature. Although many buildings in Costa Rica have active fire protection measures, they are commonly not implemented or used properly rendering them insufficient.

4.1.6 Fire-Rated Materials

In Costa Rica, fire-rated materials are not used as often as they should. There are many buildings that don't have any passive fire protection measures, especially the older buildings in Costa Rica. If they were constructed before 2005, the buildings have very little, if any fire-rated materials. There are also many examples of fire-rated materials not being properly used during recent construction or renovations. In many instances, the architects and builders do not follow the recommended assemblies to properly install fire-rated materials which should be provided by the material vendors. By not following these assemblies, the fire resistance time of the materials is degraded. For example, we visited a local hospital, where there was a visual lack of firestopping in the building. The hospital is around 50 years old and was constructed with low ceilings which can't properly house the IT wires. For renovations and technical upgrades, many of the wires and systems are then brought below the ceiling with no firestopping at the holes of exit and entry. The holes allow for fire to spread vertically to the floors above. Having a hole in an assembly significantly diminishes its fire-rating. Another issue with materials is when the builders leave the Styrofoam slabs for the concrete in the final building. These Styrofoam slabs are a risk for fire, they are highly flammable and can create very toxic fumes if burned. Although fire-rated materials are very readily available in Costa Rica, they are not always being used or properly installed during construction.

4.1.7 Emergency Protocol

We found that emergency protocol is more important in large communal buildings such as hospitals. We had the pleasure of interviewing members of the engineering and architecture departments of two different hospitals. Both hospitals were public, which meant there was a large amount of people visiting them each day, with patients housed there as well. This meant that there needed to be a protocol in place if there was ever an emergency such as an earthquake or fire.

We collected information from both hospitals that included various drills, calling emergency responders, and fire brigades. In the first hospital, we found that there was a practice emergency drill held only once a year, which meant if an employee was not working that shift, they would not be up-to-date with the protocol. In the second hospital, we obtained knowledge on their fire drills as well. The second hospital had fire drills, but not often. Instead, they include a fire extinguisher training course in employee orientation, which was retaken every five years.

As for the evacuation plans, neither hospital had a set standard of evacuation. The evacuation plans were not well-planned out and not communicated thoroughly. For the public, the standard evacuation plan is to follow the signs that are posted around the hospital that point out the means of egress, which are prepared by the architects during construction. The standard of evacuating patients is to move them from their rooms to a safe compartment with fire-rated materials that range from 1 to 2 hours. Both hospitals did not have these fire-rated compartments, so there was no evacuation plan in place. For example, when there was an earthquake at one of these hospitals and the nurses and doctors felt the earthquake, they immediately evacuated the buildings and left the patients inside. Only after the nurses and doctors knew that they were safe were the patients attended to.

Emergency protocols ensure that people will know what to do in the event of a fire or earthquake. If structures with large occupancies do not have these plans in place, it can cause panic from people inside these buildings.

4.2 Construction Budget Analysis

After a careful analysis of three different construction budgets, we concluded that the inclusion of fire protection measures in accordance with *NFPA 101 Life Safety Code* causes a budget increase of 3%–6% of the total construction budget. While this may seem like a high cost, most construction budgets are in millions of dollars, and 3%–6% is a very small increase, especially when considering the benefits of installing fire protection,

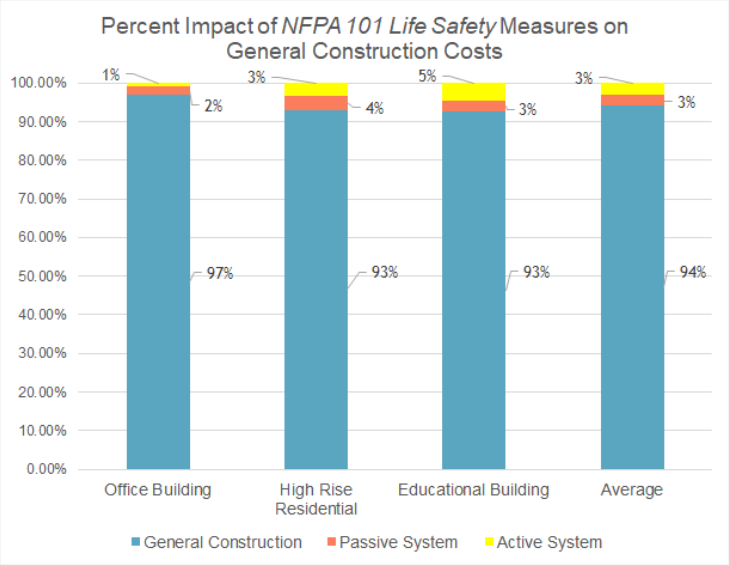


Figure 13. Graph Based on CFIA Provided Construction Budgets showing percent increase caused by Fire Protection measures

like minimizing fire damage in buildings and most importantly saving the lives of the occupants and firefighters. During our analysis, we considered the active system, as well as the passive system including doors, walls, and ceilings. The figure shows the increase that purchasing fire-rated materials causes and doesn't not account for the cost of the wall, door or ceiling that would already exist.

4.2.1 Social Impacts

The greatest social impact we noticed in interviews was that professionals think that there is a significant increase in construction budgets when fire protection measures are included. We asked our informants and they all agreed that there was a large increase in cost when buildings were built with fire protection measures. They pointed out examples such as an expensive active system, redesigns and increased costs after Bomberos inspections, and fire-rated door assemblies. According to the Bomberos, most buildings are designed, then the fire protection systems are included, rather than the initial plans being designed with fire protection in mind. This method will cut down on design hours and potentially unnecessary fire protection materials that could have been excluded had the building been designed with fire protection in mind. Designing a building and considering fire protection during the initial design greatly cuts down on the unforeseen costs further along in the process and makes the fire protection aspect of a construction project go more smoothly. This finding also requires a remedy, as this misinformation is taken as fact throughout the building industry.

4.2.2 Economic Impacts

The economic impact of this finding is hard to quantify. While we have proven that fire protection measures do not greatly increase construction budgets, there is the potential for unforeseen costs during construction, such as a change to plans because of a Bomberos inspection or if something is improperly designed and must be remedied before construction. To mitigate these costs, it is important for engineers and architects to be well acquainted with the NFPA codes, and to ensure that they design buildings with fire protection measures the first time. Increasing NFPA knowledge improves the outcome of Bomberos inspections and ensures that buildings are built in accordance to *NFPA 101 Life Safety Code and* will ultimately save construction and design costs.

4.3 Lack of NFPA Education

A common topic in our interviews with various stakeholders was the lack of education about the NFPA codes. Some people knew what the NFPA codes were and could reference them but could not apply them in their designs and work. Others knew nothing of the codes and implemented other forms of fire protection in their designs. The stakeholders that informed us of this finding were people with architecture and engineering backgrounds that are in the building industry.

4.3.1 Social Impacts

The lack of NFPA code knowledge in Costa Rica presents a large problem within the social aspects of society. We discovered the problem is not with building professionals ignoring the NFPA codes and refusing to incorporate the codes into their designs and buildings, but with the scarcity of knowledge of the NFPA codes in Costa Rica. Individuals in Costa Rica with engineering and architecture backgrounds who want information on the NFPA codes needed to go elsewhere than the university at which they studied at. We found through our conversation with one professional civil engineer that the university where he studied at offered an "emphasis" on active fire protection methods particularly for students in the mechanical engineering department. This "emphasis" would include courses that demonstrated the design and application of water sprinkler systems. We found through our interviews that out of all the courses in the universities, the "emphasis" on fire protection methods was the only course offered that considered with fire protection.

It was a common theme from our interviews with various experts that the same university mentioned in the previous paragraph offered no knowledge on the passive system, which are important and mentioned throughout the *NFPA 101 Life Safety Code*. Since the passive system includes some of the frameworks of the buildings such as walls, doors, and ceilings, the responsibility for incorporating quality fire-rated materials in the buildings that comply with *NFPA 101* belongs to the architects. Various architects confirmed that they had no knowledge of the *NFPA 101* while studying in their universities as no classes covered the material. Architects claimed they learned about *NFPA 101* only after the failed inspections of some of their work, at some point after their graduation from universities.

After students graduate with degrees in their respected field, knowledge of NFPA codes is acquired through self-motivation. We were told by several professionals that many architects and engineers enter the work field with little ambition for further knowledge for the betterment of their career. The few that go through the extra schooling have several options that can help

them understand NFPA codes such as the Life Safety Code. One option is to take NFPA courses on specific codes from NFPA instructors. Although there are few instructors in the Latin America area (Mr. Hernandez is one of them), it is possible to enroll in such classes, whether it be in the United States or in Latin America. Another option for knowledge is courses offered by material companies promoting their products, such as United States Gypsum (USG) and Allegion. These companies offer preparation courses for their customers in order to explain and encourage building professionals to use their products. The last option we consulted was to take classes offered by the CFIA twice a year. Very few architects and engineers take advantage of these resources to increase their knowledge of *NFPA 101*. Those that do are ultimately able to include their newfound knowledge in their designs and buildings.

Furthermore, NFPA chapters in Latin America are not effective and are not very active in spreading fire prevention awareness. These chapters provide little support in terms of advancement of knowledge within Latin America. Some professionals did not even know that these chapters existed. While a good first step in adopting NFPA codes in other countries is to start an NFPA chapter, little progress is made if chapters tend to be unsupportive of their members and do not contribute towards improving NFPA education in these Latin American countries.

There is also a risk to buildings caused by the public regarding life safety and their lack of knowledge throughout their everyday life. Without knowing, some maintenance workers or employees put their building at risk through bad practices around the building. Examples include blocking means of egress with boxes and clutter in the hallway, putting flammable or combustible materials in a room where there is electrical equipment, or putting decorations such as plants in front of fire extinguishers. Furthermore, we were told by architects and engineers that the public are not concerned with NFPA codes and are more aware of the seismic code. They said the reason of this is because earthquakes affect a large amount of buildings, whereas fires only affect a few neighboring ones. This may make sense in the eyes of the average person, but in fact more people die from fire than from earthquakes every year in Costa Rica. Many professionals explained that the misinformation and bad practices could be prevented if people were aware of some fire preventive measures and the dangers of materials in hazardous zones.

4.3.2 Economic Impact

The lack of knowledge of NFPA codes can cause some economic impacts to Costa Rican society as well. Public education in colleges and universities in Costa Rica is free of

charge to students. However, the courses taught by the NFPA, some distributors, and the CFIA mentioned above in the previous section can be expensive. The NFPA charges $1100 to attend their *NFPA 101* seminar, and the CFIA charges $500 for the same seminar. We were told that some college students with architecture and engineering backgrounds are more drawn to working and learning in the field rather than paying money to take courses on *NFPA 101 Life Safety Code* and other relevant codes. Through various circumstances, having knowledge of the NFPA codes will help architects and engineers save money for their projects. One circumstance could include following *NFPA 101* in the beginning of the design to save any monetary problems that may arise through construction with inspections or failures. Also, the lack of education can lead to wasted billable hours with architects redoing designs to comply with codes and result in someone trying to self-perceive the NFPA codes, not fully understanding them, and trying to implement them into their buildings. These problems can add extra cost to the project due to the lack of knowledge of NFPA codes.

4.4 Conflicting Information Between Bomberos Manual and NFPA Codes

Regarding the multiple fire protection practices that building professionals incorporate in the infrastructure in Costa Rica, the NFPA codes and the Bomberos Manual consistently were topics of conversation. The NFPA codes and standards were adopted in Costa Rican law in 2005. This law includes the Bomberos Manual, which is based on NFPA codes and acts as an explanatory handbook. Even though this law is in place, Bomberos constantly reference the Manual in their work. Between these two sources, there is some conflicting information that causes confusion in design, construction and inspections of buildings.

4.4.1 Social Impacts

The Bomberos introduced their Manual at some point after the NFPA codes were adopted countrywide. The purpose of the Manual was to act as a

> “guide that establishes the basic requirements for reducing the risk of fire that every building must comply with such as to provide the occupants with adequate and reasonable protection in case of emergency...It is an explanatory manual, based on the NFPA standards, so that if it is necessary to deepen on a particular subject or a specific occupation, you should consult the original standard” (Bomberos, 2013).

Under the law, the Manual has some exemptions to the NFPA codes and standards. Some builders, architects and engineers, and even the Bomberos themselves regularly reference the Manual in their work. The Manual is not originally intended to act as a reference, but as a guide or handbook to explain some fire protection measures. However, we were told by the Bomberos that this Manual was an attempt to simplify and “tropicalize” some of the NFPA

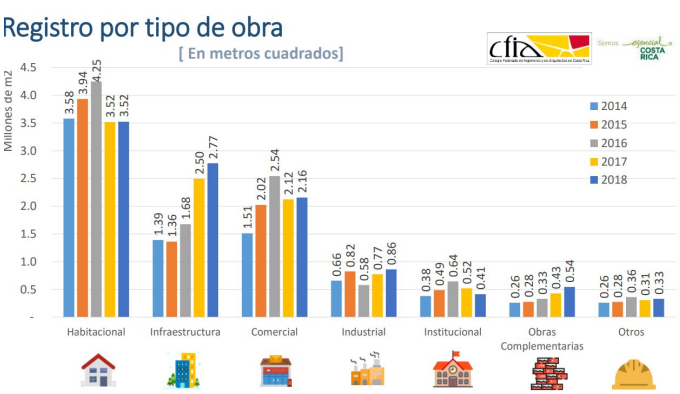


Figure 14. Types of Registered Buildings through the CFIA (cfia.or.cr)

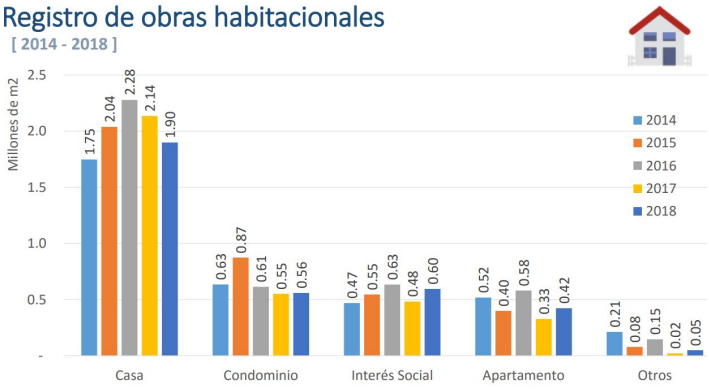


Figure 15. Type of Residential Buildings Registered through the CFIA (cfia.or.cr)

codes and that they were trying to make the Manual into a local code itself. The Bomberos anticipated updating the manual every year, however they are currently using the 2013 edition of the Manual, with a new edition set to be published this year (2019). The NFPA authorities have told the Bomberos many times that there is no need for the Manual, and that the NFPA codes will supersede all others as long as it remains the law.

Some parts of the NFPA and Manual agree since the Manual is based on NFPA codes, but other parts do not, which causes confusion. We were told from various professionals with some NFPA code background that the attempt to “tropicalize” the code has made buildings more vulnerable to fire. The Manual includes a section on the use of water sprinklers in certain areas of buildings. We were told that buildings that are 2500 m^2 or less do not need a water sprinkler system installed. Also, the Bomberos do not inspect small residential buildings, which is one of the largest categories of registered buildings in Costa Rica according to the CFIA.

One of the scenarios where the conflicting information of these two sets of documents is most prominent is with the Bomberos’ inspections during and after construction. Through many interviews with material vendors, architects and engineers, developers, and the Bomberos, we obtained an understanding of the Bomberos’ inspection process. The inspections include a report of observations they have seen throughout the building and result in a passed inspection or failed inspection. The developer or owner of the building will be notified of the results on the status of the building. Then, these inspection reports get passed on to the Ministry of Health,

who acts as the enforcer in this process and can close buildings as they deem necessary. Although the Ministry of Health reviews the construction documents that come from the Bomberos, the Ministry does not employ any fire protection engineers who specialize in fire protection systems. This process has the capability of turning into a loop at any point if the building fails. Afterwards, it must be resubmitted correctly one additional time or the process starts from the beginning again.

Throughout these inspections, we were told by almost all the professionals to whom we spoke that the Bomberos are inconsistent in their reports. We were made aware that the Bomberos use the Manual to review the construction documents before construction, then during the construction process use the NFPA codes and standards. These codes are used interchangeably during the construction process which leads to failed inspections for some of the buildings. This results in increased costs more often than not. The Bomberos ask for things according to their criteria but they do not have standard criteria to reference and give suggestions and inspections using the NFPA codes and Manual interchangeably.

Furthermore, the Bomberos are short on staff and do not fully understand the NFPA codes especially *NFPA 101 Life Safety Code*, which lead to undetailed and unfinished inspections. Leaving one problem in a building that was unidentified during an inspection can result in a risk, and that risk can turn into a problem quickly. We found that the Bomberos are very good at inspecting the active system within buildings. Many components of the active system such as fire extinguishers and sprinkler systems are inspected and updated as they see necessary. However, we found that the problem with the inspections is that the Bomberos mention very little concerning the passive system in their reports, mentioning only problems with means of egress and doors. We were told from several professionals that the Bomberos do not focus on ceilings, floors, or walls in their inspections. These materials help to compartmentalize the fire into a single space for a tested amount of time, which allow people to exit the building. These materials must be included in the report because a building could comply with all the active system, but if the buildings lack the passive system, it will still burn down. The Bomberos have little knowledge on the passive system because there is not a lot of public knowledge of those systems in Costa Rica. The Bomberos often ask for detailed and time-consuming plans of the building, not only for a review of it but also for them to begin to learn about the passive system from the architects who design them.

4.4.2 Economic Impacts

The inconsistency of the Bomberos' construction document review and inspections can cause economic impacts for the people funding the building projects. In most cases, the Bomberos initially approve the documents with the manual and then use NFPA codes during inspections. This causes developers and contractors to spend more money to change the deficiencies pointed out by the Bomberos. Most of the time developers and contractors do not make any claims against the Bomberos even though some of the equipment the Bomberos ask for is not needed according to the NFPA codes. A reason for not filing claims against the Bomberos is because these claims take a long time to process, and this can result in wasted billable hours. During an interview with a developer we were able to visit an automated-type parking structure. The Bomberos informed the developer that a water sprinkler system was required to be installed inside the parking garage. According to the most updated form of *NFPA 88A Standard for Parking Structures*, it states that "*NFPA 13 Standard for the Installation of Sprinkler Systems* at this time does not describe how to protect automated-type parking structures." The Bomberos, who did not know this, told this developer the building needed these systems, resulting in an added cost of around one million dollars. Situations like these have a major part in forming public opinion that the implementation of NFPA codes is too expensive.

4.5 Difficulties with Existing Buildings Complying with *NFPA 101 Life Safety Code*

Many existing buildings in Costa Rica do not comply with *NFPA 101 Life Safety Code*. It can become very difficult or expensive to update already-built buildings to comply with *NFPA 101 Life Safety Code*. Costa Rica adopted the NFPA codes and standards in 2005, which means the construction of most buildings is not compliant with NFPA codes that were built before 2005. There are many issues, social and economic, that affect the implementation of NFPA codes in buildings that are 15 years old or more. Fire protection measures were not widely spread throughout Costa Rica, making these existing building absent of passive fire protection measures.

4.5.1 Social Impacts

There is a social impact with the difficulties of existing buildings that do not comply with *NFPA 101 Life Safety Code*. The main social impact of getting existing buildings to comply with *NFPA 101* is time. Renovating and updating buildings to include fire protection measures can be a slow process, especially in large, populous buildings such as hospitals. Most hospitals in Costa Rica are under constant renovation in attempt to have relevant technology, equipment,

and procedures. While seeking the new technology and equipment, the renovation must also include fire codes, standards, and safety measures due to national law. Only small sections of hospitals can be renovated at one time, due to the hospital having to stay fully operational. This makes the process of updating buildings slow and frustrating for the engineers and architects involved, as the buildings are typically far from compliant and have many issues that are only discovered during construction.

4.5.2 Economic Impacts

The economic impact of renovating existing buildings to comply with *NFPA 101 Life Safety Code* is monetarily substantial, especially when comparing existing and developing buildings' attempts to comply with NFPA code. To update the existing building, it will cost substantially more to renovate than to develop a new building that complies with *NFPA 101*. Although it is very expensive, it is also required by law for renovations to comply with the code. From visiting two hospitals, and interviewing the engineers, architects, and life safety officers of the hospitals, we were able to acquire information on renovating already existing buildings.

We visited and interviewed a local hospital in Costa Rica that is around 50 years old and is under constant renovation in an attempt to comply with the *NFPA 101 Life Safety Code*. Being an old building, it was initially built under regulations when fire protection code did not exist. The hospital has many physical limitations which include low ceilings, old electrical systems, disorganized water pipes with unknown destinations and no compartmentalization of areas. The architects struggle to find a way to compartmentalize the hospital due to the ducts and the messy electrical lines in the ceiling. This makes it very hard to build barriers and compartmentalize the building through these systems. Having an already existing building with many of these limitations causes higher cost of renovation because architects must develop new solutions when trying to incorporate *NFPA 101*. The hospital is under constant renovation, so the economic issue is the architects and engineers are always waiting for money to renovate. These physical limitations are encountered quite regularly when renovating older structures and can cost substantial amounts of money.

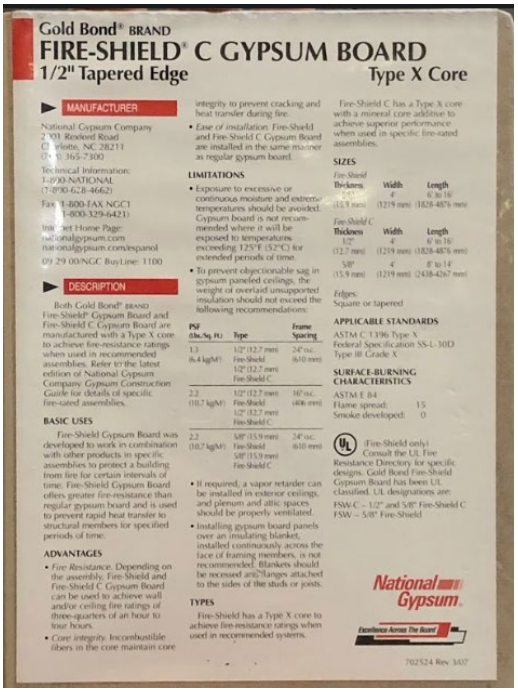
4.6 Availability of Fire-Rated Materials

The use of fire-rated materials in buildings is crucial in the success of *NFPA 101 Life Safety Code*. When the life safety code was designed, NFPA tested certain materials to achieve fire, heat and smoke resistance. As the code is updated, NFPA continues to test materials to improve results of fire resistance. The use of fire-rated materials throughout a building and for

means of egress will protect the building and evacuation routes for people to exit during fire. While in Costa Rica, it was important for us to examine how available fire-rated materials were and if materials vendors were promoting the use of fire-rated materials.

Through multiple interviews with material vendors and through research, we found that there is a large selection of fire-rated materials that is available throughout Costa Rica. We found that many types of firewall systems, fire doors, ceiling systems and floors are easily accessible for project teams to utilize. During one of our interviews, we analyzed many different types of fire-rated drywall that a material vendor offers. They offer a range of different drywall systems for different code requirements. In an interview with a different material vendor, we found that they offer many different types of fire doors and ceilings. Even in an interview with a general contractor, it was stated that fire-rated materials are readily accessible. Fire-rated materials are easily accessible in Costa Rica, but it is up to the engineers and architects to design for these materials, and for the developers and contractors to utilize these materials. We found that many professionals in the field, architects and contractors, are not fully aware of how accessible fire-rated materials are. We also found that most material vendors are not prepared to sell fire-rated assemblies and do not have enough knowledge in the field. The sections below will discuss the social and economic impacts of having easily accessible fire-rated materials and some impacts of using these materials.

4.6.1 Social Impacts


Gold Bond® BRAND
FIRE-SHIELD® C GYPSUM BOARD
1/2" Tapered Edge
Type X Core
MANUFACTURER
DESCRIPTION
BASIC USES
ADVANTAGES
LIMITATIONS
SIZES
APPLICABLE STANDARDS
SURFACE-BURNING CHARACTERISTICS
TYPES
National Gypsum

Availability of fire-rated materials in Costa Rica has social impacts on multiple groups throughout the construction process. Through our interviews with material vendors, we found that they offered many different types of fire-rated materials. Apart from having a large selection of materials, we found most material vendors are not prepared to sell fire-rated assemblies. One material vendor that we interviewed (one of the largest in the country) was much more prepared to sell fire-rated assemblies and more knowledgeable in the field than most other material vendors in the country. This impacts the designers and

Figure 16. Specification Sheet for Gypsum Wall Panel showing type of Fire resistance (By Authors)

contractors who reach out to the material vendor about certain fire-rated materials. Material vendors who are prepared and trained to sell full fire-rated assemblies ensures that the designer is using systems that are up to code.

Having fire-rated materials easily accessible in the country gives designers the ability to design buildings without worrying about the availability of certain materials. One of the material vendors interviewed has a large selection of drywall, including National Gypsum Fire-Shield C Gypsum Board Type X (pictured), Sheetrock Fire-Shield drywall, USG Gypsum Firecode drywall, and many others (Featured Products, n.d.). Most of their drywall selection had Underwriters Laboratories (UL) testing certifications. UL is one of the largest testing facilities in the world. The UL certification is shown on the product label, as shown, along with other characteristics. Another material vendor we interviewed has a large selection of fire doors and fire-rated ceiling assemblies. The material vendors said if an engineer or architect specifies a product and the vendor does not have it stock, they will order it and it will arrive in 6-8 weeks. Most of the materials used for construction are imported, but it is possible for designers to have access to any fire-rated materials that the *NFPA 101* asks for. Having fire-rated materials easily accessible impacts the designers of the projects so the designers are able to comply with *NFPA 101* and its' specifications on material use. Along with the availability of materials impacting the designers, this impact runs through a chain of people throughout the construction process. Having easily accessible materials also impacts the developers and contractors, as they are able to build their building in accordance with *NFPA 101*. When a building is fully constructed in accordance with *NFPA 101,* this directly impacts the life safety of occupants in the building. The use of tested fire-rated materials will protect means of egress in order for occupants to evacuate during fire. Although the benefits and impacts of using fire-rated materials are evident, we find that professionals are not always aware of the availability of materials. A large portion of architects and contractors do not understand that fire-rated materials are easily accessible, due to their lack of knowledge and due to lack of knowledge on the part of most material vendors. Many professionals also do not understand the requirements of using fire-rated materials, which stems from a lack of knowledge of NFPA code.

Through interviews with material vendors, engineers and architects, we found that fire-rated material selection is much easier for commercial buildings than it is for residential buildings. Another way our team measured the availability of fire-rated materials was to visit one of the largest hardware stores in the country. It did have fire-rated materials, but the selection was not very broad, and the testing labels were either missing or hidden. Many residential and small apartment projects will use hardware stores for materials (rather than commercial building

material suppliers), and the availability of fire-rated materials there is restricted. This directly impacts contractors working on residential projects. It also impacts occupants living in these houses or apartments.

4.6.2 Economic Impacts

Along with social impacts, there are a number of economic impacts with having available fire-rated materials in the country. Using fire-rated materials will impact cost, but as discussed earlier, not by much. Many professionals in the field have a misconception about cost of fire-rated materials. During interviews with hospitals in Costa Rica, the architects and engineers claimed that using fire-rated materials throughout the large hospital is too much of an economic burden. One of the hospitals, which is one of the largest public hospitals in the country, believes that new fire-rated ceilings and coatings would be too expensive. During an interview with a material vendor who sells ceiling assemblies, they believed the price difference of fire-rated ceilings is a 25% increase. Through our research, we have found that the cost of implementing *NFPA 101* is not a substantial cost and having fire-rated materials easily accessible makes that cost even lower. When designers and contractors do not design for fire-rated materials due to limited understanding of the availability of materials, this impacts the cost of renovation. It is a much higher cost if a building has to be renovated in order to comply with code, then to originally design the building up to code. If designers and contractors fully understand how easily accessible fire-rated materials are and understand how to apply *NFPA 101*, we find that there is not a substantial impact in cost.

5.0 Recommendations

The following chapter provides a summary of the findings determined through our research, interviews and budget analyses while in Costa Rica, and delineates the four recommendations we have created to remedy the issues that Costa Rica is experiencing with implementing the *NFPA 101 Life Safety Code* in its building industry.

5.1 Findings Summary

During our time in Costa Rica, we found four major themes during our interviews that help to uncover the issues in the implementation of *NFPA 101 Life Safety Code* in Costa Rica. We have summarized these themes in the next several sections to provide background for the recommendations that follow.

5.1.1 Consistent NFPA Deficiencies in Costa Rican Buildings

Many of the buildings in Costa Rica have noticeable deficiencies in the NFPA codes and standards. Many buildings we visited had deficiencies in both active and passive components of the fire protection system. There were many examples of insufficient parts of the passive system in buildings, including signage, means of egress and material selection. There were insufficient parts of the active system as well, including fire extinguishers, sprinklers, and emergency protocols. Buildings were more compliant with the active system than passive system. These inadequate components of the fire protection system were indicative of the lack of knowledge of *NFPA 101* throughout the country of Costa Rica.

5.1.2 Construction Budget Analysis

The budget analysis we completed on the four construction budgets revealed that 3%-6% of the cost of a building is dedicated to fire protection systems. Most professionals in the field believe that fire protection greatly increases the costs of a buildings. Additional costs can occur if a building is designed without some aspects of the NFPA code that must be added later, or if the Bomberos detect any errors with the design or construction. However, if engineers and architects consider the fire protection systems required by the NFPA during the initial design stages, they can mitigate most of these potential issues by ensuring the building is designed correctly according to the code. Additional money can be saved if the building is designed to avoid superfluous fire protection materials. The major issue with this finding is that every professional to whom we spoke believed that fire protection measures caused a significant cost

increase, despite never doing their own budget analysis. Additionally, fire protection can cause an increase in cost if there are any issues of compliance caused by either a lack of knowledge from the professional or from conflicting information from the Bomberos.

5.1.3 Lack of Education in Universities regarding NFPA Codes

Throughout our interviews we were able to conclude that many professionals lack knowledge of the NFPA codes. Some professionals had some knowledge on the NFPA codes, especially the *NFPA 101 Life Safety Code*, but did not know how to apply the code in particular situations. While there is some opportunity to obtain knowledge of the NFPA codes, it is not properly advertised or required for some of these professionals to design and work on buildings. The local universities in Costa Rica incorporate an emphasis on fire protection, however, the courses involved only focus on implementing the active fire protection system and ignore the passive fire protection system in buildings. The passive system, which are required under *NFPA 101,* are responsible for keeping the fire contained in one area in order for occupants to evacuate. Incorporating the passive system into buildings starts with the architect in the designing process. Various architects revealed to us throughout our interviews that they had little knowledge of *NFPA 101.* Few architects and engineers look elsewhere for knowledge beyond their university training such as NFPA instruction, classes offered by the CFIA, or courses offered from material distributors.

Furthermore, the lack of knowledge of the NFPA codes can cause a large monetary increase for certain projects. Failing to incorporate NFPA codes into the designs can cause wasted billable hours fixing construction documents, or even trying to implement a self-perceived concept of fire protection, without fully understanding it. Alternatively, architects with knowledge of *NFPA 101* are able to incorporate its contents into their designs, which keeps the project on time with no extra costs regarding fire protection equipment. Without professionals with proper education of the NFPA codes, which are part of the law, some buildings will be built unsafely.

5.1.4 Conflicting Information between Bomberos Manual and NFPA Code

We were able to discover through our interviews that there was a conflict of codes within designs and inspections in Costa Rica. In 2005, Costa Rica passed a law that required buildings be built with the NFPA codes and standards. The same law allowed the Bomberos, the fire department of Costa Rica, to create an explanatory Manual based on basic NFPA codes and standards that includes some exemptions to the NFPA codes. Through our research we

discovered that the Bomberos, architects and engineers, and builders have been using the Manual as a reference, even though the Manual is specifically a guide. The Bomberos have said that the Manual is an attempt to “tropicalize” the NFPA code and their aim is begin to make it a countrywide code.

While reviewing plans and during inspections, the Bomberos are inconsistent with the criteria they use. In many occasions, the Bomberos review construction documents and inspect buildings with the NFPA codes, the Manual, and the local construction code interchangeably. The use of different criteria for different buildings creates confusion on the construction site and in the design rooms. The Bomberos often call for equipment in buildings that are not needed, resulting in a large cost increase to projects. Professionals that are meant to implement the observations made by the Bomberos rarely make claims against them. The claims can take time to process, ultimately resulting in wasted billable hours for the construction projects.

Stakeholders discussed with us that the Bomberos usually conduct a thorough inspection on the active system of buildings, but fail to inspect most of the passive system within buildings. A building with a compliant set of the active system will fail to contain a fire without the passive system inside a building. Although the inspections were thorough on fire doors and means of egress, they lacked the knowledge to inspect walls, ceilings, and floors. The lacking materials are important contents in making buildings compartmentalized. Ultimately, the Bomberos’ inspections cause building professionals to spend time and money on implementing their observations, even though their observations are based on different criteria.

5.1.5 Difficulties with Old Buildings Complying with *NFPA 101 Life Safety Code*

Buildings constructed before 2005 in Costa Rica do not comply with NFPA Codes. Renovating older buildings to meet NFPA standards costs a substantial amount of money, effort, and time. It especially costs more money when comparing old and developing building’s attempts to comply with the NFPA code to a new building that incorporated NFPA code in their early design stages. Old buildings usually have years of repair work and structures that are not suited to implement the NFPA codes, making them hard to renovate following the codes. Renovating old buildings also takes time and, can be a very slow process, especially in large populous buildings where on-going renovations can affect the production or productivity. It is expensive, difficult, and time consuming to update old building in adherence with NFPA codes.

5.1.6 Availability of Fire-Rated Materials

Through our interviews and research, we were able to conclude that fire-rated materials are easily accessible in Costa Rica. Material vendors offer many types of fire-rated assemblies for project teams to utilize. Fire wall assemblies, ceiling assemblies, and fire doors are all available throughout Costa Rica. Most of the materials are imported, but according to material vendors, it takes 6 – 8 weeks to arrive in the country. Although the materials are available, most material vendors are not prepared and knowledgeable enough to sell fire-rated assemblies. This impacts the designers and contractors who reach out to the material vendor about certain fire-rated materials. The availability and use of fire-rated materials impacts many groups throughout the construction process. It impacts the designers and contractors' abilities to easily use these materials and to comply with *NFPA 101.* When a building is built in accordance with *NFPA 101*, it impacts the life safety of occupants in the building. Even though fire-rated materials are available, we conclude that many professionals in the country do not understand the use of fire-rated materials and do not know how easily accessible fire-rated materials are. This is indicative of the lack of NFPA knowledge concerning the use of fire-rated systems in the country.

5.2 Recommendations

Our recommendations are as follows:

1) The CFIA should publicize information on budget analyses of fire protection, which demonstrate that fire protection systems are not a major cost burden.
2) The Bomberos must respect the purpose of the Explanatory Manual and eliminate the goal of making the manual its' own local code.
3) The CFIA, CIEMI, and especially CACR should a) promote NFPA courses, seminars and workshops within the country; b) encourage their members to attend them and apply the knowledge; c) and work with the NFPA to ensure that courses are easily accessible.
4) The Ministry of Health and Bomberos should a) improves the inspection process; b) clarify the order of authority within the building industry; c) employ more certified professionals to ensure that buildings are in compliance with NFPA codes.

5.2.1 Promote Accurate Cost Information Regarding Fire Protection Materials

As seen in the findings chapter, we were able to successfully show that the inclusion of fire protection systems causes an increase of 3%-6% of the total budget, a very small increase when most construction budgets are in the millions of dollars. However, this information is of no use if no one in the building industry is aware it. Therefore, we recommend that the CFIA, and

the CACR use the graphs and visuals we have developed to help promote this information. By promoting these graphics, visuals and more importantly, the information that they depict, we anticipate that professionals in the industry will decrease using the fact that they're concerned about increased costs as an excuse to not implement proper fire protection measures. By eliminating this prejudice, we anticipate that there will be fewer roadblocks in ensuring that fire protection measures will be included in buildings, thus making both buildings in Costa Rica and the general public safer. This information can be promoted by using visual evidence through seminars and trainings with architects and engineers within the Colegios, and meetings with executives and leaders within the Colegios. It is most important that this information is disbursed accurately and with the backing of CFIA, so that the professionals take stock of the information.

5.2.2 Clarifying Manual

After thoroughly analyzing our data from multiple stakeholders involved with the construction process, we were able to make a recommendation based on the standing of the Bombero's Manual. We recommend that the Bomberos eliminate the goal of making the Manual a code and clarify that the Manual is an explanatory guide that establishes basic requirements for reducing the risk of fire in every building. We also recommend that the Bomberos use the NFPA codes in all forms of review and design to ensure a consistent standard for all to follow. We believe that if the Bomberos are more consistent about the NFPA codes and what materials and standards must go into buildings based on these codes, then knowledge of the NFPA codes will improve in the building industry.

Referencing the Manual as a code in place of the NFPA codes during the construction process not only complicates the designs and inspections but adds time and cost to the project. It also adds an unknown part of the construction process for owners and developers, not knowing what new problems will arise, such as the water sprinklers in the automated parking garage example. Furthermore, making the Manual a national code will require time and manpower that we observed the Bomberos do not have. This is shown in the attempts to update the Manual over the past years. The Bomberos are currently using the 2013 edition of the Manual, even though it is supposed to be updated every year. Updating literature and adding more information to succeeding editions is critical, especially when life safety is being considered. These updates require time and manpower to ensure that the new tests and new materials are valid and safe. While the NFPA has over 6,000 committees working on constantly revising the NFPA codes every year, the Bomberos only a small fraction of that capability. We recommend that the Bomberos rely on the NFPA codes and standards in their reviews and

inspections to keep things consistent in construction. In order to complete this recommendation, the Bomberos must realign their goals with conducting reviews and inspections and ensure that all field inspectors are familiar and can apply NFPA codes in the conditions they are in, particularly the passive system.

5.2.3 Strengthen NFPA Knowledge

The CFIA, Colegio de Ingenieros Electricistas, Mecánico e Industriales (CIEMI), and especially the Colegio Arquitectos of Costa Rica (CACR) need to promote NFPA courses, seminars, and workshops within the country, encourage their members to attend these courses, and to work with the NFPA to ensure that courses are easily accessible to the architects and engineers. Additionally, the CFIA should require that every practicing architect in the Colegio take NFPA courses, in order to provide motivation to improve knowledge within the industry. There is a lack of knowledge throughout Costa Rica about the NFPA codes and standards. It would improve the fire protection in the nation if there was push for education on the NFPA codes by higher organizations like the CFIA.

The CIEMI and CACR need promote the courses offered by the NFPA to address the widespread lack of knowledge about them. There are many scheduled courses this year (2019) in Costa Rica from both the CFIA and NFPA. The courses held by the CFIA are around half the price of courses offered by the NFPA. This is an opportunity for these colleges to promote NFPA codes to the architects and engineers in Costa Rica. CACR could try and schedule more NFPA courses throughout the year as more architects and engineers attend. Finally, CIEMI and CACR also need to encourage the architects and engineers to follow and learn about the NFPA codes, otherwise the only pressing factor is from the Bomberos inspections, which aren’t always accurate to the code.

The NFPA has many different types of learning materials to offer in Costa Rica. The NFPA offers all of its codes translated into Spanish, catering to Latin America. With all of the materials they have to offer, the CIEMI and CACR need to strongly promote these materials on to engineers and architects of Costa Rica.

5.2.4 Ministry of Health

We recommend that the Ministry of Health and Bomberos improve the inspection process, clarify the order of authority within the building industry, and employ more certified professionals to ensure that buildings are complying with NFPA codes. As expressed in our findings chapter, the construction process and inspections done by the Bomberos do not fully

encompass the goals of *NFPA 101 Life Safety Code*. The use of the Bomberos manual has undermined the use of NFPA codes and standards during the design and construction process. Inspections are a key element in ensuring that *NFPA 101* is implemented and sustained.

The Costa Rican Ministry of Health is responsible for regulating the healthcare industry in Costa Rica (Costa Rica Ministry, n.d.). The Ministry of Health regulates the safety of building in order to ensure that occupants are protected. They also hold the power to issue operational and occupancy licenses, based on the Bomberos' observations regarding new construction. Implementing and maintaining *NFPA 101* is crucial in protecting occupants inside buildings. When the Bomberos inspect buildings and construction documents and pass observations to the Ministry of Health, we recommend that the Ministry review those inspections more thoroughly and take more responsibility for compliance of *NFPA 101*.

In order to accomplish this, we recommend that the Ministry of Health should clarify the order of authority within the building industry. Through multiple conversations with professionals, we learned that the order of authority with implementation and maintenance of *NFPA 101* in buildings is believed to be unclear. The Bomberos have too much authority with implementation and maintenance of the code and we believe they do not have enough knowledge and manpower for the entirety of it. We recommend that the Ministry of Health, as an embodying leader, should clarify the order of authority it has over the review of construction documents.

An additional recommendation we have for the Ministry of Health and Bomberos is to employ more certified professionals to ensure compliance of *NFPA 101*. Trained and knowledgeable professionals working for the Ministry of Health will improve inspection reports and put more responsibility on the Ministry. Utilizing more NFPA trained engineers will ensure the Bomberos are inspecting buildings correctly based on *NFPA 101*. The benefits and advantages of the code are evident as expressed throughout our report, and we highly recommend the Ministry of Health and Bomberos place more emphasis within the department on NFPA code enforcement.

6.0 Conclusion

The goal of this project was to determine the monetary impact of the addition of fire protection systems in accordance with the *NFPA 101 Life Safety Code*. An additional goal was to understand the prejudices against this code that were held by most of the professionals in the industry in order to create a comprehensive plan to improve NFPA code compliance in Costa Rica. We also examined the confusion surrounding the Bomberos Manual, which impacts the outcome of construction document inspections and field inspections in varying ways, and has significant cost impact.We developed recommendations intended to improve NFPA education in Costa Rica and to promote the knowledge that implementing fire protection is not a prohibitively large financial burden. We made recommendations to encourage the Bomberos to eliminate the goal of making their explanatory manual a code and to ensure that the manual remains exclusively a handbook to explain the NFPA codes. Lastly, we made recommendations to the Ministry of Health to become more involved in fire inspections and to hire qualified fire protection engineers to improve the inspection process.

In speaking with various professionals, including architects, developers, engineers, and material vendors, our team was surprised to discover the true extent of misinformation surrounding NFPA codes and standards. This is a major issue in the country of Costa Rica, as *NFPA 101 Life Safety Code* cannot be adequately implemented due to a multitude of reasons expressed throughout our report. Our WPI project team hopes that our findings and recommendations will provide the Colegio Federado de Ingenieros y Arquitectos de Costa Rica with strong and tangible evidence for the future.

Works Cited

Ahrens, M. (2016). High rise building fires. Retrieved from https://www.nfpa.org/News-and-Research/Data-research-and-tools/Building-and-Life-Safety/High-Rise-Building-Fires

Álvarez Eduardo, D.Use of NFPA standards as references in argentina. *NFPA Journal LationAmericano,* (2018) Retrieved from http://www.nfpajla.org/archivos/edicion-impresa/nfpa-desarrollo-adopcion-de-normativa/843-utilizacion-de-las-normas-nfpa-como-referentes-en-argentina

Arcila Julian.La adopción de la normativa de NFPA en américa latina . Retrieved from www.nfpajla.org/archivos/edicion-impresa/nfpa-desarrollo-adopcion-de-normativa/821-la-adopcion-de-la-normativa-de-nfpa-en-america-latina

Associated Press. (2005, 7/12/). 18 die in costa rica hospital fire. Retrieved from http://www.nbcnews.com/id/8551431/ns/world_news-americas/t/die-costa-rica-hospital-fire/#.W99Z8JNKg2x

Biesanz, M. H., Biesanz, R., & Biesanz, K. Z. (1999). *The ticos: Culture and social change in costa rica*. USA: Lynne Rienner Publishers.

Black star line restaurant. Retrieved from https://www.tripadvisor.com/LocationPhotoDirectLink-g309264-d3961699-i65883318-Black_Star_Line_Restaurant-Puerto_Limon_Province_of_Limon.html

Buchanan, A. H., & Kwabena Abu, A. (2017). *Structural design for fire safety* John Wiley & Sons.

CFIA. (2014). *Ausencia de permiso municipal de construcción en 23% de obras [absence of municipal building permits in 23% of works].* (). CFIA: CFIA Comunicado De Prensa. Retrieved from http://cfia.or.cr/descargas_2014/noticias/ausencia_permisos.pdf

CFIA logo. Retrieved from http://cfia.or.cr/

CIMA hospital (2019).

Coffman, B. (2013). Code enforcement: Critical for a successful fire prevention program. Retrieved from https://www.fireengineering.com/articles/print/volume-166/issue-01/features/code-enforce-critic-success-fire-prevent-prog.html

Colegio Federado de Ingenieros y de Arquitectos de Costa Rica, [CFIA].Estructura [structure]. Retrieved from http://cfia.or.cr/quienesSomos.html

Commercial finishes. Retrieved from https://alumimundo.com/comerciales/

Costa rica ministry of health overview. Retrieved from https://www.emergobyul.com/resources/costa-rica/ministry-health

Ed Wonsek.*Photos of WPI quad *

Featured products. Retrieved from http://www.macopa.com/

Fire code. Retrieved from https://encyclopedia.thefreedictionary.com/fire+code

Fox Valley Fire & Safety Services. (2013). The importance of NFPA codes and standards. Retrieved from https://www.foxvalleyfire.com/2013/11/the-importance-of-nfpa-codes-and-standards/

Goodier, R. (2005). New fire codes draw criticism Retrieved from http://www.ticotimes.net/2005/07/29/new-fire-codes-draw-criticism

Henfling, I. (2015, September 18,). Several reasons to build a house in costa rica without a permit.*Godutchrealty.Com,* Retrieved from https://www.godutchrealty.com/costa-rica-real-estate-blog/costa-rica-construction/several-reasons-build-house-costa-rica-without-construction-permits/

Hernández, H. (2019). *Personal interview*

Inside Costa Rica. (2012). Costa rica gets its' first electrical code. Retrieved from https://www.insidecostarica.com/dailynews/2012/august/14/costarica12081407.htm

Life Safety Services. (2015). Passive fire protection vs. active fire protection. Retrieved from http://news.lifesafetyservices.com/blog/active-vs-passive-fire-protection-2

Natalie Oxford.*Photo of grenfell tower *

National Fire Protection Association, (NFPA). (2005). *Nfpa 1.* ().NFPA. Retrieved from http://modares.ac.ir/uploads/Shr.Technical.Rar.101.pdf

National Fire Protection Association, [NFPA]. (2018). NFPA code activity. Retrieved from https://www-nfpa-org.ezproxy.wpi.edu/about-nfpa/international/code-activity

NFPA. (2013). Seven people die each day in reported U.S. home fires. Retrieved from https://www.nfpa.org/News-and-Research/News-and-media/Press-Room/News-releases/2013/Seven-people-die-each-day-in-reported-US-home-fires

Palin, M. (2017). Grenfell tower: Why it hasn't collapsed. Retrieved from https://www.news.com.au/world/europe/grenfell-tower-why-it-hasnt-collapsed/news-story/7c71ab28f57c4c073d4bcf78aa1e79db

Photo of higgins lab building

Photo of WPI athletic fields

PreventionWeb, & (N.D).Basic country statistics and indicators(2014). Retrieved from https://www.preventionweb.net/countries/cri/data/

Puchovsky, M. (2018). *Personal interview*

Ronan point. Retrieved from https://en.wikipedia.org/wiki/Ronan_Point

Tavares, R. M. (2009). An analysis of the fire safety codes in brazil: Is the performance-based approach the best practice? *Fire Safety Journal, 44*(5), 749-755. doi:10.1016/j.firesaf.2009.03.005

UL Saftey Index. (2018). *Overview: Safety performance in costa rica* . ().2018 Underwriters Laboratories Inc. Retrieved from https://ulsafetyindex.org/

Unifour Fire & Safety. (2017). Common causes of commercial fires. Retrieved from https://www.unifourfire.com/blog/common-causes-commercial-fires

The wake of the black star line. (2016). Retrieved from https://www.nacion.com/viva/cultura/la-estela-del-black-star-line/HMTXSQ3JNFF7XLTVWHYK2V2V3E/story/

WPI logo. Retrieved from https://www.wpi.edu/sites/default/files/inline-image/Offices/Marketing-Communications/WPI_Inst_Prim_FulClr.png

Appendix A: Interview Questions

Material Vendors Interview Questions

1. What kind of materials do you offer buyers?
2. What is your most popular product? Why?
3. Are any of the materials you provide fire rated? Percentage? If so, which ones?
4. Which are your most popular fire-rated products? Why?
5. Do you know if your products have certifications from laboratories?
6. Which laboratories?
7. Do engineers and architects ask for these certifications?
8. Are fire rated materials easily accessible in Costa Rica?
9. Is there usually a big price difference between materials that are fire-rated and materials that are not fire-rated?
10. Do you encourage engineers, architects and contractors to purchase fire safe materials if two comparable options are available?
11. What do you do if an architect or engineer asks for a fire-rated material and you do not have it in stock?
12. Do engineers and architects usually go for price or quality?
13. Is it harder to sell fire-rated products to architects? Engineers? Why?
14. Do you personally believe that most buildings are made with quality fire-rated materials or built with cheaper materials that are combustible?

Hospital Interview Questions

1. What is your role at the hospital?
2. How old is the hospital? How much renovation has been done?
3. When designing and updating this building, what codes do you follow?
4. If they follow other than NFPA 101, how does it compare to NFPA 101?
5. What is your role in ensuring this building follows codes?
6. Have you taken the NFPA 101 preparation courses?
7. What is the biggest challenge with adhering to NFPA 101 at this hospital? In general?
8. In your opinion, does adhering to NFPA 101 increase construction costs? By how much?
9. What life safety measures do you have in the hospital?
10. Is there a protocol in case of an emergency?
11. Are the employees trained to know the location of exits, meeting points and protocols?
12. Have the buildings ever been inspected by the Bomberos?
13. Have you ever received an observation report following an inspection?
14. Have you altered your buildings in anyway by this report? How?
15. Do you see any risks in the building that could cause fire?
16. Has there been any past fires in the Hospital
17. What are your thoughts on value engineering? Do you feel it happens often in Costa Rica?
18. Do you feel this building is safe?

Developer Interview Questions

1. About how many buildings/projects have you developed?
2. What is your education background?
3. Do your buildings have an emergency insurance policy?
4. Are you familiar with the NFPA 101 Life safety code?
5. If yes, have you taken any NFPA 101 preparation courses?
6. Do you know if your buildings were designed and built in accordance to NFPA 101?

7. What life safety measures do they include?
8. Do the buildings employ a safety officer?
9. Are the building occupants aware of any fire protection measures?
10. Do your buildings have an evacuation protocol in the event of a fire?
11. Have your buildings ever been inspected by the Bomberos?
12. What are some observations they frequently make?
13. Are the changes that they observe hard to implement? Expensive? Time consuming?
14. Once you change the construction documents according to the Bomberos review, are you aware if there are any aspects that are missing?
15. Do you think that the Bomberos review ask for too much? What do you feel is too much?
16. During the construction process, Do you notify the Bomberos and CFIA of any changes made to building?
17. Do you think that NFPA 101 is asking for expensive solutions? Which parts are too expensive?
18. Have you ever done a budget analysis on the requirements of the NFPA?
19. Ask about if he encountered NFPA in his college classes in america
20. Do your buildings have meeting points

CFIA Interview Questions

1. How long have you been an in this field?
2. Are you familiar with the Codigo de Seguridad Humana 101 code?
3. Have you taken the Codigo de Seguridad Humana 101 preparation courses?
4. What are some advantages of fire code?
5. What are some disadvantages of fire code?
6. Does adhering to fire codes drastically increase construction costs? If yes, why?
7. Have you designed any buildings that are up to the Codigo de Seguridad Humana 101 fire code?
8. Which buildings?
9. Based on your experience, and knowledge of the fire codes, are most buildings in San Jose code compliant? If not, could you offer a rough estimate or percentage of those that are?
10. Do you feel most buildings in this city are safe?
11. Do you see a lot of fire rated materials in the plans you review?
12. What is your role in code enforcement in Costa Rica?
13. What are your thoughts on the local fire code manual that the Bomberos made to incorporate the NFPA codes into Costa Rican infrastructure. Good idea or bad idea?
14. Do you personally believe this manual fully encompasses the NFPA goals for safety?
15. Why do you think people don't follow NFPA fire code?
16. What do you think could be done to improve this?
17. What are you thoughts on value engineering? And how often do you think it happens on a construction site?
18. Are there any incentives that you think could help motivate people to follow NFPA fire code?
19. We were told through our recent interviews that some people lack the knowledge of fire prevention because it is not taught in universities, would you be involved in that process? How difficult/expensive would it be to implement fire protection programs into universities?1
20. What are your thoughts on providing some sort of incentive such as education of fire and life safety codes?
21. When was seismic code adopted?

Bomberos Interview Questions

1. How long have you been in this profession?
2. What do you do/what is your affiliation with the bomberos?
3. Are you familiar with the Codigo de Seguridad Humana 101 fire code?
4. Have you taken the Codigo de Seguridad Humana 101 preparation courses?
5. Have you applied the Codigo de Seguridad Humana 101 in any situations? If so, which ones?
6. What are some advantages of fire code?
7. What are some disadvantages of fire code?
8. Do you think adhering to fire codes drastically increases construction costs?
9. If yes, why?
10. Can investing in fire codes save money if a fire occurs?
11. Have you inspected any buildings that are up to the Codigo de Seguridad Humana 101 fire code?
12. How does your role work with the Secretary of Health to inspect buildings?
13. What is the main type of communication you have with buildings in emergencies? (things like phone, radio, smoke alarms auto-dialer)
14. On average, how many fires occur each year?
15. On average, how many commercial building fires or large residential fires do you respond to a year?
16. What is the most common cause of building fires that you respond to?
17. Are there any major fires that you recall that helped motivate fire code adoption?
18. Are you familiar with Codigos (70, 72, 54, 58, 13, 14, 20, 99)
19. Based on your experience, and knowledge of the fire codes, are most buildings in San Jose code compliant? If not, could you offer a rough estimate or percentage of those that are?
20. Do you feel most buildings in this city are safe?
21. Is active or passive fire protection more important?
22. Can you explain more in detail the manual Bomberos has created from the NFPA code.
23. Do you personally believe this manual fully encompasses the NFPA goals for safety?
24. Why do you think people don't follow NFPA fire code?
25. What do you think could be done to improve this?
26. Are there any incentives that you think could help motivate people to follow NFPA fire code?

Construction Authority Interview Questions

1. What are your roles in the CCC?
2. Can you explain the permitting process that a building owner goes through?
3. Are you familiar with NFPA 101?
4. What percentage, rough estimate, of buildings in Costa Rica are built in accordance with NFPA 101?
5. How does the following of NFPA 101 impact the construction industry?
6. Do you think adhering to NFPA 101 increases construction costs?
7. Do you feel that one specific fire-rated system is too expensive?
8. How do Bomberos inspections impact the construction industry?
9. What are the most common observations Bomberos make?
10. Do you believe that fire-rated materials are easily accessible in Costa Rica?
11. Are the construction documents often changed during construction process?
12. What are your thoughts on the Bomberos manual?

13. How would you compare the Bomberos manual to the NFPA codes and standards?
14. Do you support the adoption of NFPA codes? Have you always? What changed your mind?
15. Have you done any sort of budget analysis on the inclusion of fire protection systems in buildings?

Appendix B – Additional Pictures of NFPA 101 Deficiencies

Table covering main exit

Open main staircase

Wall does not go from floor to ceiling slab, enables fire to travel between even fire-rated rooms

No fire stopping

Figure 6 Styrofoam slab

Fire Hazard - Objects covering exit

Diffuser, sprinkler and smoke alarm not following NFPA distance specifications

Means of egress not protected in any way