IRB-21-0177

High-rise Façade Fire Safety

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

December 11, 2020

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Abstract

The purpose of this project was to assist Jensen Hughes in analyzing the technical and social aspects related to high-rise building fires, specifically in relation to their facades and the usage of aluminum composite panels. To accomplish this, we began with a secondary analysis of data gathered from multiple sources on building fire case studies and common testing practices used in the fire protection industry. We then conducted a series of interviews with professionals in the realm of fire safety and façade material testing in order to gather technical data from first-hand sources and review social outlooks on high-rise façade fire safety. We determined that while ACP has the potential to be a safe and reliable material, there are many problems still found in the fire safety world which need to be addressed before it can be deemed a completely safe material to use.

Acknowledgements

This project and the resulting report would not have been possible without the support and collaboration of individuals from Worcester Polytechnic Institute and beyond. We would like to express our gratitude to Aaron Vanney of Jensen Hughes for sponsoring this project, being the primary source of information on high-rise fire safety, and for informing decisions on what directions to take our project. A great thanks is also due to our project advisor, Professor Joseph Doiron for providing us with guidance and assistance throughout our project, as well as allowing us this opportunity and assisting us in our project proposal.

We would also like to thank the following individuals and organizations for sharing their knowledge and expertise on fire safety and related topics to help us achieve our goals:

- Professor Aaron Sakulich, Civil and Environmental Engineering at WPI
- Professor Leonard Albano, Civil and Environmental Engineering at WPI
- Professor Milosh Puchovsky, Fire Protection Engineering at WPI
- Thomas Bell Wright Labs
- Michael Slocumb, FM Approvals
- Michael McMahon, FM Approvals

We would also like to acknowledge the invaluable contributions of all parties who assisted in the making of this project.

Executive Summary

Introduction

Aluminum Composite Paneling (ACP) is a widely used exterior cladding on building facades and has achieved widespread usage on high-rise facades worldwide. It is commonly used for its aesthetics, durability, price, and insulation properties but is also known to have a flammable polyethylene core. There have been multiple cases in the past decade where major fires occurred on high-rise and ACP was the primary culprit for the severity of the fires.

ACP has been extensively inquired about since the Grenfell Tower Fire. The Grenfell Tower fire occurred on June 14th, 2017 and had a total of 72 fatalities. After this event, a judge-led inquiry on the fire was announced by the British Prime Minister Theresa May. (Grenfell Tower Inquiry, 2019)

In order to fully understand the social and technical effects ACP usage has, it is also important to understand the development and testing procedures it goes through. These tests must be designed by trusted fire protection professionals and be able to establish the safety of a material before it is used. They must also be up to codes and standards followed by most private and public organizations. These can include codes and standards set by reputable sources such as the National Fire Protection Agency, or the International Code Council. (National Fire Protection Association, n.d.)

Methodology

The goal of this project is to analyze the social and technical effects of ACP on high-rise façade fire safety. In order to do this, we did a combination of secondary analysis and interviews coded using grounded theory to give us an overview of how ACP is used and viewed in the fire protection and construction industry.

The secondary analysis came from our background research into case studies of high-rise fires, codes and testing standards, and the chemical and physical properties of high-rise façade materials. The data from this was then coded thematically into several groups and from there we developed the topics and questions for our interviews.

The interviews were conducted with a variety of professionals in the fire protection field, ranging from professors to insurance companies. After each interview, the transcript was coded to establish a theory which builds off a previous theory formed from our background research and previous interviews.

Findings

From the interviews conducted, key knowledge regarding ACP use, fire safety, and associated societal problems was gained. Beginning with the materials, we found many alternative materials including, but not limited to solid aluminum sheets and glass.
Another important finding was that experts did not agree on the most detrimental cavity wall size. From analyzing testing standards, we gathered that there are two types of tests, reactive and preventative testing. One new testing standard found was FM 4411, which was a reactive test measuring flame propagation within cavity walls. Such a testing standard was found to have been developed in the wake of fires around the world.

One important note from our interview with someone who lived through a façade fire was how afraid everyone became as a result. People began buying home insurance and lawsuits were filed. As a result of the interviews, we gathered that the way people look at fire safety around the world varies on a large scale. For example, in Singapore, there aren't any sprinklers installed in their buildings, they rely on non-combustible materials to stop the spread of the fire. As for the public response, people and engineers view codes as a minimum requirement to complete. From our interviews, we found the societal problems include, but are not limited to unincentivized owners and contractors, as well as the lack of material traceability. Traceability refers to taking a material from a building and finding its exact composition in addition to its properties and manufacturing process.

Conclusion and Recommendations

From our data collection and thematic coding, we were able to draw up several conclusions that we used to help develop our recommendations. One of the major findings was the fact that ACP can be safe relative to other façade materials when used correctly. Correct usage includes development with non-combustible cores that allow the panels to retain their advantageous properties, such as aesthetics and maintainability, without being a major fire hazard. Another point of correct usage is the installation of the panels. When installed correctly along with the fire stops allowing them to work as one assembly, the risk of major flame propagation is greatly reduced. From this, we were able to craft our first recommendation: halt the use of low-density polyethylene (LDPE) in high-rise façade paneling. LDPE is a commonly used plastic that can usually be found in the core of ACP. However, it is also extremely combustible and has been the culprit of many major high-rise façade fires in the past few decades. Halting the use of this material as an ACP core would greatly reduce the risk of a major façade fire.

Our second finding was the lack of uniform fire codes throughout the US and globally. Although there are organizations dedicated to researching and developing excellent fire codes such as the NFPA and the ICC, these tend to be recommendations rather than requirements. Our second recommendation discusses the possibility of a federal organization to establish adequate fire codes around the nation to ensure they are all up to standard and are effective for their locations.

One discussion point in some of our interviews was about the traceability of materials, and how it is a challenge to know and understand exactly what your materials are and where they came from. This can create challenges with specifying if your materials are up to code or not. Creating a chain of traceability and labeling would help mitigate this issue and allow for a full understanding of what materials are used in the facade assembly.

Correct installation leads into another finding we had, which is the lack of regard and understanding of many fire protection codes and standards. Many times, problems occur when engineers and designers do not have a full understanding of the codes they implement into their buildings. This can cause serious problems, because a major aspect of an effective fire code is an effective implementation of it. When they are viewed more as problems or hurdles it is possible to incorrectly utilize the codes and standards making them almost inert. Our final recommendation refers to incentivizing engineers and contractors to gain a full understanding of codes and standards. This would cause fire codes to be implemented properly and work uniformly in an assembly rather than be viewed as costly hurdles.

Authorship

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1. Introduction

In the early hours of June 14th, 2017, a small fire broke out in a flat in Grenfell Tower, a 25-story high-rise located in London, England. (Brulic and Dzidic, 2018) Within two hours, the fire had spread to engulf nearly the entire building, leaving dozens of people trapped. By the time the fire burned out over 24 hours later, over 70 people had died as a result of the fire. This fire garnered international attention to try and determine how a high-rise located in a modern first world country could have such disastrous results and such a failure of fire safety. (Grenfell Tower Inquiry, 2019)

A little over a year before the fire, renovations had been completed on the high-rise to install a new façade onto the building. This façade was mainly composed of aluminum composite panels (ACP), a sandwich panel which has a polyethylene core sandwiched between two thin sheets of aluminum. ACP had become commonplace in the construction industry within the past few decades because of its versatile aesthetics, durability, price, and insulation properties. However, it was also known that the polyethylene core of the material was extremely combustible. (Grenfell Tower Inquiry, 2019)

The goal of this project was to investigate how ACP is viewed in both the building industry as well as the fire safety industry. From there we would provide recommendations for how to improve fire safety revolving around high-rise facades, specifically in relation to ACP. To achieve these goals our objectives were:

- Conduct a series of interviews with fire safety experts to garner an understanding of their views and recommendations
- Analyze former case studies and research done on ACP and other high-rise façade materials to understand their physical and chemical properties

We used a series of interviews which we then coded using grounded theory to help establish a basis for our recommendations. Our interviews and secondary analysis were coded into themes which we then organized onto a continuum with one end being technical aspects and the other being social aspects.

From here we drew up our conclusions and recommendations to help improve the fire safety of high-rise facades and allow for the safe usage of ACP. Our findings found ethical problems in the views of many engineers and designers relating to their perceptions of building codes. There were also issues found with the development and installations of some ACP materials, specifically with Low Density Polyethylene. Our recommendations include incentivizing engineers and designers to understand the reasoning behind fire codes and standards rather than seeing them as a hinderance. We also recommend that ACP materials be fully understood by developers and contractors to ensure proper testing and installations.

2. Background

This section introduces high-rise buildings, their rise in popularity, aluminum composite panels (ACP), their usage, and the reasons why they can be considered a safety hazard. The first section discusses the need for high-rise buildings and the key technological breakthroughs that allowed for their proliferation.

2.1 High-rises

With the exponential growth of human population in recent history, mixed with the growing population of cities in the past centuries, high-rises have become an increasingly popular building choice worldwide. For this project, we have chosen to use the definition of 'high-rise' as given in the 2014 New York Building Codes: A building with an occupied floor located more than 75 feet (22.86 m) above the lowest level of fire department vehicle access. (NYC Building Code, 2014) New York City has thousands of high-rises and has a history of high-rise development, prompting us to choose this definition.

High-rises have been around for centuries, but modern high-rises with iron frames only became apparent in the mid-19th century. (Gifford, 2007) Buildings like the Flatiron incorporated steel skeletons to allow higher buildings to be constructed compared to masonry. In addition, the steel skeleton allowed for thinner walls at the base to support the loads, freeing up precious interior space, while keeping a stone exterior (Condit, 1982).

With these modern high-rises came a multitude of other building facets, one of them being building façades. Building façades are the exterior of a building and does not provide structural support to the building but adds protection against the elements. Over the years, the materials used for façades has changed. At the start of the skyscraper, façades were constructed using stone or terracotta. Since around World War II, façades have switched to using glass; new technology allowed large sheets of glass to be produced more economically (Jester and Tomlan, 2014)).

When it comes to fire safety in early skyscrapers, there was not much. Cast iron columns were often unprotected and wood floors offered kindling for fires. This meant that buildings would often collapse. Innovations around the turn of the century would allow skyscrapers to be built even higher and fireproofing became more prevalent. Steel columns would be welded or riveted together and were then incased in concrete. In addition, floors were built with tile instead of wood, which increased fire resistance and lowered the heat transfer between floors (Craighead, 2009).

2.2 Aluminum Composite Paneling

Aluminum composite paneling, or ACP, is a commonly used material in the building and construction industry, specifically as a cladding for building facades. It is a "sandwich panel" meaning it is composed of a plastic core, usually some form of polystyrene, polyurethane, or polyethylene, sandwiched between two thin aluminum sheets. (Byrnes, et al., 2019) (Chen, et al., 2019) The aluminum sheets tend to be around half a millimeter thick with the core being around 3 millimeters thick. They are bonded together using some form of adhesive which may vary with the manufacturer. (Chen, et al., 2019)

Figure 1: Two-dimensional Aluminum Composite Panel Diagram
(Presutti, 2020)

ACP was developed in the 1960's and by 1969 the modern form of ACP cladding was being produced by the company ALUSINGEN. The patent was owned for 20 years from 1971 to 1991, and upon the expiry of the patent ACP began to be produced by multiple companies allowing its usage to become much more widespread and beginning the massive popularity of the material. (Mohaney & Soni, 2018)

The popularity of ACP mostly comes from its aesthetics and versatility. It is able to come in many different shapes and sizes, as well as be sold in a variety of different colors. It is easy to use and install as well as simple to maintain. (Byrnes, et al. 2019) It provides adequate protection from the environment as well and is resilient to many natural forces such as wind, precipitation, and sunlight.

One of the most popular cores for ACP is polyethylene, a synthetic thermoplastic polymer that has a high calorific value causing it to be a fuel source for most fires. It has a melting point of 130-135^{o}C and has an ignition point of 377^{o}C. When melted it can produce burning droplets if ignited causing a fire to spread. Low Density Polyethylene is a version of polyethylene cores that has small air bubbles within it to help improve the insulation properties but can also cause fires to be much more severe as they allow more oxygen in to fuel the fire.

Aluminum has a melting point of approximately 660^{o}C which can cause it to melt and warp during a major fire. (Grenfell Tower Inquiry, 2019)

2.2.1 Usage and Assembly

ACP is primarily used as a façade material, where it is used to complete the "building envelope". It provides no real structural support; its main role is in protecting the building from the elements. There are many ways ACP can be assembled onto a building. One way they are attached is by leaving a gap between the paneling and the structural wall. This is called a cavity wall. The cavity has multiple functions; the air itself provides extra thermal conductivity. Another function is if any rain gets behind the cladding, the cavity wall will act as a second barrier to the structural components and guide the water to be drained. These are the main benefits of a cavity wall. (Jamison and Boardman, 2016)

With cavity walls, especially those without fire stops, are more susceptible to widespread façade fire damage. This is because the chimney effect makes flames propagate inside the cavity much higher than they would compare to flames on exterior. This is the main drawback of cavity walls. (Jamison and Boardman, 2016)

2.2.2 Benefits

There are many benefits to using ACP. ACP is a cost-effective material as well as being relatively low maintenance. The popularity of ACP mostly comes from its aesthetics and versatility. It can come in many different shapes and sizes, as well as be sold in a variety of different colors. It is easy to use and install as well as simple to maintain. (Byrnes, et al. 2019) It provides adequate protection from the environment as well and is resilient to many natural forces such as wind, precipitation, and sunlight. Additional layers can be added to the panels to ensure this protection as well as allow for a glossy finish on the aluminum sections. (Mohaney and Soni, 2018)

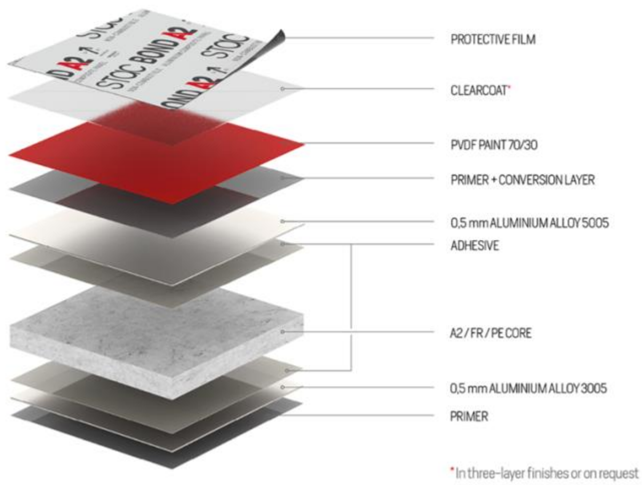


Figure 2: A layered diagram of a STAC BOND ACP product

(STACBOND, n.d.)

Another benefit of ACP is the insulation properties it provides. Aluminum does not provide much insulating value with a specific heat around 0.800 J/g at room temperature. The core, on the other hand, is the core is the main contributor to the insulating values. Low-density polyethylene has a specific heat of 2.9 J/g. In the grand scheme of materials, this combination does not provide much insulation, but it is a benefit (Ronca, 2017).

2.2.3 Detriments

ACP can have a large range of cores. There are cores that are fire resistant, but there are cores that are very flammable. A variety of these plastic cores such as low-density polyethylene (LPDE) or expanded polystyrene (EPS), have the potential to be extremely combustible when put under the right conditions. This is the main detriment of using ACP, the inclusion of flammable cores in the material. The most notable cores that are flammable is polyethylene, which is one of the most common plastics used for the core in the sandwich panels. The panel is especially flammable if the polyethylene is low-density. This is because there are air gaps in the composite that provides extra oxygen to the fire. (Grenfell Tower Inquiry, 2019)

2.3 High-Rise ACP Fire Case Studies

With the rise of ACP usage in the last few decades came many cases of high-rise fires involving the cladding. Along with these fires have come multiple reputable case studies based upon them discussing the implications of the properties of ACP and how they affected the spread and intensity of the flames. Three of the major fires include the Grenfell Tower Fire in London England, the Torch Tower Fires in Dubai, and the Lacrosse Building Fire in Melbourne, Australia, all of which utilized ACP as a building façade when the fires occurred.

2.3.1 Grenfell Tower Fire – London, England

Grenfell Tower was a high-rise residential building located in North Kensington of London, England. It was originally completed in 1974. The tower was 25 stories and was primarily made of concrete with a reinforced concrete core, floors, and columns. The building façade originally comprised of concrete panels and sliding aluminum framed windows. The window infill panels were white and composed of concrete.

Figure 3: Grenfell Tower before the renovations
(Grenfell Tower Inquiry, n.d.)

Between 2011 and 2013, renovations were carried out to replace the doors on residential rooms with up-to-date, code compliant fire doors. From 2012-2016, the tower was renovated to provide new cladding in the form of ACP. The panels had a 3mm thick Polyethylene core sandwiched between two 0.5mm aluminum sheets.

The panels were also shaped into “cassettes” which allows the m to interlock vertically more easily. The panels were attached to several components on the concrete façade and an entirely new external wall was created. The panels were attached with small gaps between other panels and the concrete surface to allow protection for rainfall but still allowing for ventilation to allow rainwater to be drained away. In some areas, polymer foam insulation was attached to the concrete wall to allow for better heat insulation of the building. The gaps between the panels and the concrete wall or insulation ranged from 139mm and 156mm.

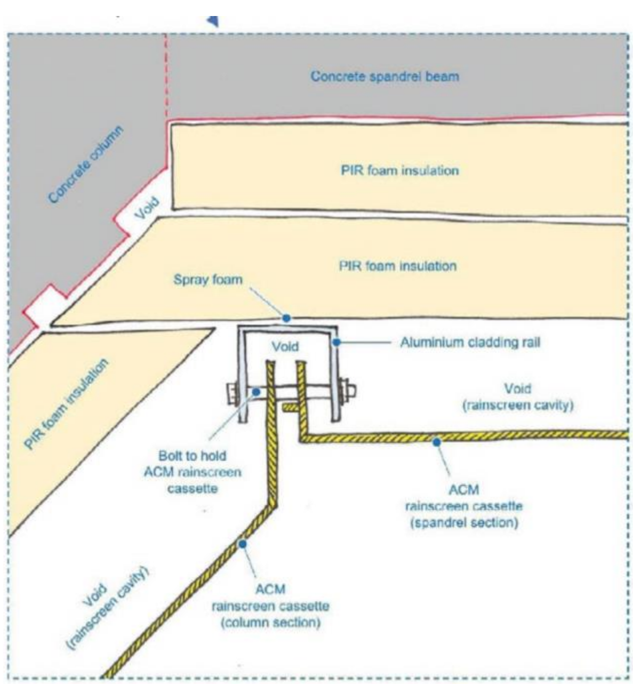


Figure 4: A cross-diagram showing insulation and ACP installation on Grenfell Tower (Grenfell Tower Inquiry, n.d.)

“Cavity Barriers” were installed in the façade assembly in order to help prevent the spread of flames in the case of an external fire. These firestops are meant to expand and seal gaps in the event of a fire and prevent the flames from escaping. However further investigation revealed that many of these barriers were not continuous or installed incorrectly, allowing for flame spread. The renovations and installation of the new façade were complete in late 2016. The fire would occur a year later. (Grenfell Tower Inquiry, 2019)

Figure 5: Grenfell before and after the renovations
(The Sun, 2018)

Just before 1 am on June 14th, 2017, a fire broke out in the kitchen of an apartment on the 4th story. The fire quickly spread to the top of the building within 30 minutes and had engulfed the majority of the upper floors by 3 am. The fire began near a freezer appliance in one of the flats. Within 15 minutes the fire began to spread to the outside of the building and eyewitness reports say that the façade surrounding the flats window caught flame. The fire began on the east side of the building and rapidly climbed to the top floors of the building where it then began to spread to the northern and southern faces of the high-rise. (Grenfell Tower Inquiry, 2019)

The tower had a policy known as ‘stay put’ where the occupants were told to stay where they were while the fire burned. The goal of this is to contain the fire to one section of the building and extinguish it without causing too much panic or mayhem. However, as the fire spread along the exterior of the building, many of the occupants became trapped where they were. By 2:47 am the policy had been abandoned. Many of the occupants had already fled the building in the beginning stages of the fire, but there were still about 130 people left in the building by the time the fire was declared a ‘major incident’ by the fire brigade. Once the stay put policy was abandoned by 2:47 am, 65 people needed assistance from firefighter to escape the blaze.

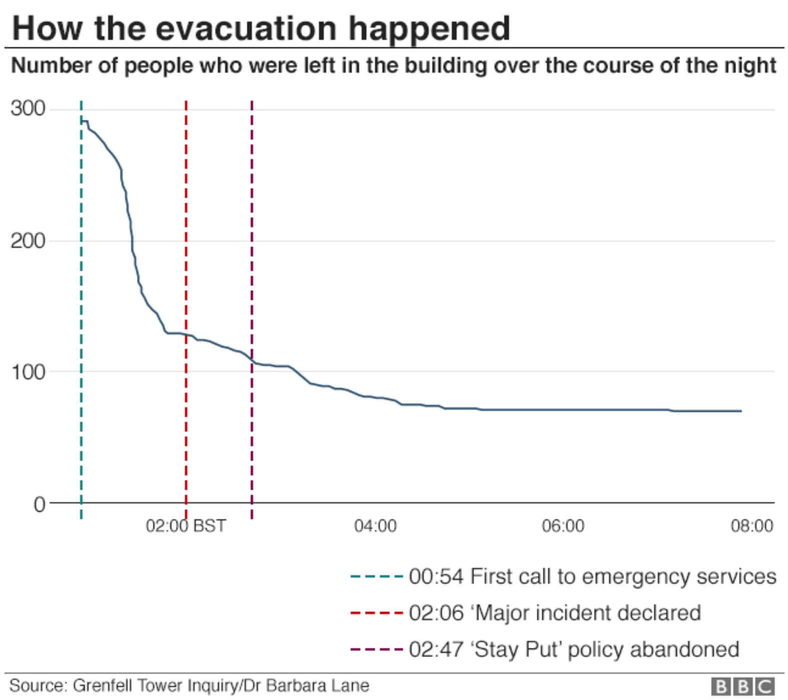


Figure 6: Graph showing the evacuation of Grenfell Tower during the fire
(BBC News, 2019)

Many residents chose to climb to the top of the building to find refuge in higher apartments as the fire began so low on the 4th floor. On the top floor of the building, 24 people died. In the end a total of 72 people died as a result of the fire. The blaze burned itself out at 1:14 am the next day.

Many experts claimed that the newly installed cladding was to blame for the severity of the fire. The combination of cavities in the façade, combustible polyethylene cores in the panels, and flammable insulation foam were the main culprits.

There were also many issues with the fire codes and standards of the building which were investigated. The doors of the majority of flats were not up to standards to protect occupants in the case of a fire. There were also inadequate water supplies for suppression and lifts that were not able to adequately assist the fire fighters and evacuating residents.

The investigation into what caused the severity and massive death toll of the Grenfell Tower Fire is still ongoing, and an inquiry has been opened by the British Parliament to assist in understanding the event. (BBC News, 2019)

2.3.2 Lacrosse Building Fire – Melbourne, Australia

The Lacrosse Building was another high-rise building that caught fire in Melbourne, Australia. It was a 23-story mixed-use building which included 15 levels of apartments. Levels 6-21 were the most effected from the fire through property damage.

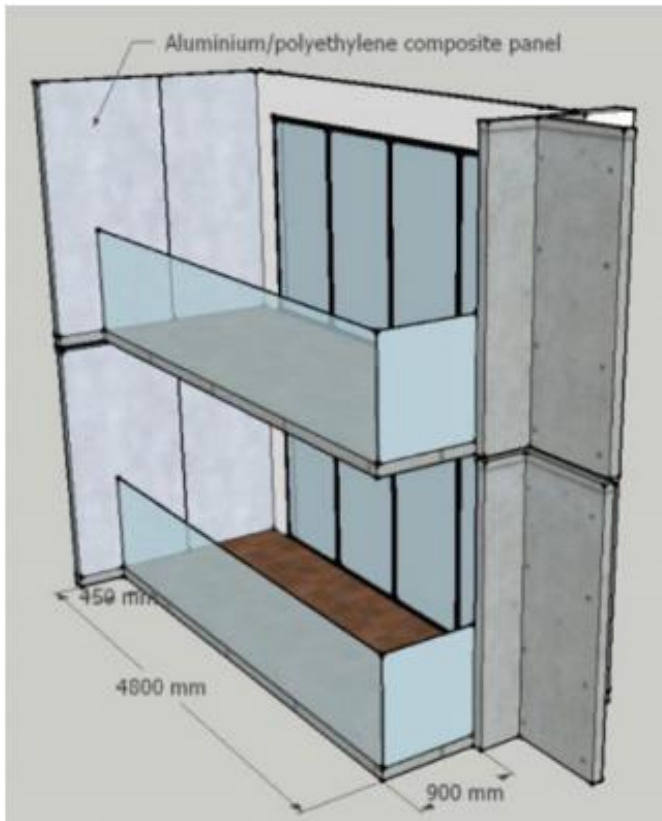


Figure 7: A model of a set of balconies where the fire occurred

.(EDP Sciences, 2014)

The fire occurred on November 25th, 2014. It originated from an 8th floor balcony and fire crews began responding to the fire around 2:24, almost an hour one of the residents living in the apartment where the fire broke out, noticed smoke. The fire spread the whole height of the building and scaled the ACP installed on the side of each balcony. (Badrock, 2016)

While the paneling is one of the reasons the fire spread so rapidly, the primary culprit for property damage was waters used to help extinguish the fire. While the sprinklers were effective in preventing the fire from spreading to the inside of the building, there was not a system in place for the prevention of fire propagation on the outside of the building. There were also problems with the fire alert systems, with many of the smoke alarms being disengaged or covered and the occupant warning system having been affected causing it to fail in many of the apartments. (Genco, 2015)

Photo Prior To Fire **Photo Post Fire**

Figure 8: Lacrosse Building before and after the fire

(City of Melbourne, 2014)

One of the reasons the Lacrosse Fire case is so important is because of the major legal battles that ensued following the fire. After the fire, a Melbourne judge ruled that owners of the apartments be paid A$5.7 million in damages from the builder, LU Simon. The judge ruled that the architect, fire engineer, and building certifier who worked on the building broke contractual obligations and must pay a majority of the sum. They pay 25%, 39%, and 35%, respectively.

It has also brought into question Australian regulations on the use of combustible materials as claddings. In the early 1990's, the Building Code of Australia relaxed regulations and allowed builders and consultants to permit the use of ACP. It is currently in discussion in the Australian government to halt the use of ACP and replace the claddings of any buildings utilizing it. (Hammer, 2020)

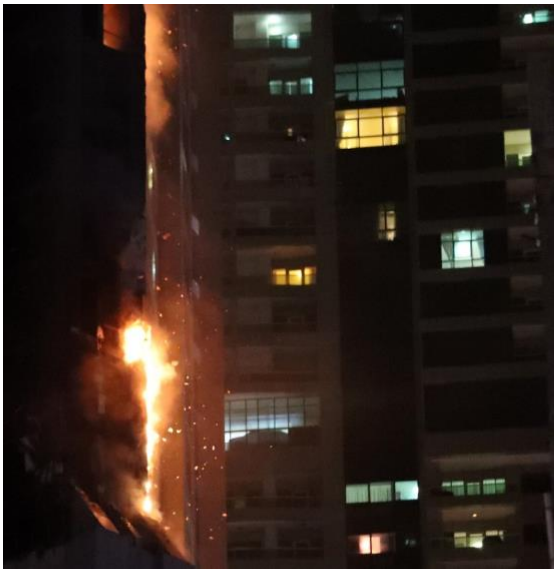
2.3.3 Torch Tower Fires – Dubai

The Torch Tower in Dubai is a 79-story skyscraper located in Dubai, UAE. It is the sixth tallest skyscraper in Dubai at 1,105 feet and was opened in 2011. It has had two major exterior fires in three years: one in 2015 and one in 2017. (BBC News, 2015)

The first fire occurred on February 21, 2015 around 2 am. It is believed to have been started by a lit cigarette or Shisha coal which burned on the 51st floor. As the fire spread along the exterior of the building, debris from the ACP panels began to fall lighting the cladding on lower floors. High winds also helped to spread the flames to the upper floors. No casualties were reported from the fire. (Bannister 2015)

The second fire occurred around midnight and burned more than 40 floors on one side of the building. The blaze was declared under control around 3:30 am. The paneling yet again was to blame for the quick spread of the fire. No injuries were reported from the fire and there was no word on the cause. (ABC News, 2017)

In both cases, adequate fire safety procedures were deemed responsible for the complete lack of casualties in the incidents. No official case studies or inquiries could be found on the fires. (ABC News, 2017)



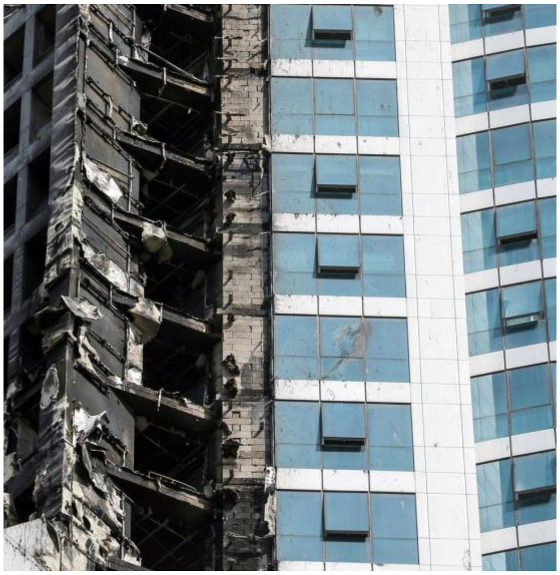


Figure 9 (Left): Torch Tower on fire for second time with falling embers
Figure 10 (right): Results of second Torch Tower fire
(BBC News, 2017)

2.4 Alternate Façade Materials

While ACP is a very commonly used façade material that has seen a rise in usage in the past few decades, there are other materials which are also used in high-rise facades that could be deemed safer and can have other benefits or detriments. These facades can either be structural, where they are made directly from the materials used to structurally support the building, or be “curtain walls”, where the materials used for the façade are attached to the structural components of the building allowing for more aesthetically pleasing and protective results. The following are three non-combustible materials that are most used as building facades today. (Façade Envelope, n.d.)

2.4.1 Masonry

One of the oldest and most commonly used façade materials are masonry bricks. They are durable to both natural elements and structural loads and give a uniform, familiar finish to most buildings. However, when unreinforced, bricks perform poorly in high-rises due to the lateral forces caused by wind and natural swaying of buildings caused by seismic disturbances. (Russell, et al. 2014) In addition, in wall load bearing situations, their bases become too large to be economical when the height of the building reaches around 15 stories. This is seen in the 16 story Monadnock in Chicago, whose walls measure almost six feet (1.82 m) thick at the base. (Sinha 2002) Unreinforced brick buildings do provide some benefits on the correct scale, most notably simplicity of detailing in drawings, no special foundational work, as well as not requiring scaffolding. When used as a façade for high-rises, they can become costly and have become outdated for newer and lighter materials which give structural support laterally while still giving an aesthetically pleasing finish. (Schaecher, 2020)

2.4.2 Concrete

Concrete is one of the most important part of modern architecture. It has been used and developed over thousands of years to allow it to be one of the most integral parts of modern construction. Many times, it is also used as a façade for buildings due to its durability, aesthetics, and sustainability. Using concrete as a façade allows for durability against many natural elements including sunlight, wind, and rain. It also allows for sustainability due to its durable nature. It does not easily degrade or deform and can last almost indefinitely when presented with the correct conditions. This can help to prevent unnecessary repairs or rebuilding. It is also cost effective, as it can double as both a façade and the primary structural support of a high-rise. It is versatile and can be poured on site or precast at a different location and shipped to the site. Concrete can also be aesthetically pleasing as it can be cast in many different shapes, patterns, and colors. Concrete has however been considered outdated in some instances and has been replaced by newer, shinier materials such as ACP. (Fontan, 2020)

2.4.3 Glass

Glass is a commonly used façade primarily due to its aesthetic. When used it leaves a uniform, glossy finish to most buildings and allows for an abundance of natural light into the building. It is also a very durable material that is easy to install and maintain. However, one of the detriments to glass is its massive energy consumption. Using glass as a façade lowers the insulation of a building, upping costs for heating, cooling, and ventilation. There are methods such as double skin glass facades which allow for better insulation and ventilation, but this can be a costly process which is still being developed and researched. (Cetiner & Özkan, 2005)

2.5 Fire Codes

Fire codes are implemented by both national and local governments around the world. Depending on the size of a nation, its physical and cultural reach, and legal consideration, nations can either decide to have a national fire code or resort to local municipalities instilling them into law. Fire codes and standards that become reference points in codes are often developed by independent safety organizations such as the International Code Council (ICC) or National Fire Protection Association (NFPA). (NFPA, 2000) Fire Codes also work in conjunction with building codes which can be classified as prescriptive or performance based. The design of new buildings is typically required to follow a prescriptive code that was adopted by the Authority Holding Jurisdiction (AHJ). Prescriptive codes require components to comply with standards while performance codes assess the function of the entire building. (Elovitz, 2019) Throughout the world, different fire and building codes aim to protect those that live and work within buildings from harm.

2.5.1 American Fire Codes

The US follows the International Building Code (IBC) when it comes to codes. Even with this, there is variation among the fire codes between the states. Regardless, for a material to be approved to be used for construction, it can either follow fire resistance specifications or pass NFPA 285. NFPA is the National Fire Protection Association. Combustible materials are allowed on buildings, but so long as they comply to the following rules. Combustible material should not cover more than 10% of the surface area where the fire separation distance is less than 5 feet (24).

2.5.2 British Fire Codes

In the UK, they use Approved Document B (ADB) to define their fire codes. This fire code differs from the code in the US because the UK focuses more on keeping the fire from spreading outside and not the flammability of the exterior. Nevertheless, there are provisions in place to deal with exterior combustible materials. ADB does identify fire resistance guidelines for cladding. The table below shows the classification of combustible materials. Another way of meeting the criteria is testing the material according to BS 8414 (British Standard) (Nguyen & et al, 2016).

Class	Definition
A1	Non – combustible. (As defined in ADB Table A6)
A2	Limited combustibility. (As defined in ADB Table A7)
B	FIGRA ≤ 120 W/s and LFS < edge of specimen and THR600s ≤ 7,5 MJ
C	FIGRA ≤ 250 W/s and LFS < edge of specimen and THR600s ≤ 15 MJ

FIGRA - fire growth rate index, LFS - lateral flame spread (m), THR600s - total heat release within 600 s

Table 1: British Standard Categorization of Combustible Materials (Nguyen & et al, 2016).

2.5.3 Worldwide Fire Codes

Australia uses the National Construction Code (NCC) as a guideline for their codes. Just like the US or UK, the material can either comply with the fire codes or pass a standardized test. In the case of Australia, they use the same test as the UK, BS 8414. That is not the only similarity between Australia and the UK. The Australians also have the same mentality when it comes to fire protection. Their codes are move focused on keeping the fire from spreading to the exterior (Nguyen & et al, 2016).

2.6 Fire Tests

One of the best ways to ensure the fire safety of both materials and assemblies is to physically test them against certain scenarios. There are several different tests from around the world that are widely accepted as the benchmark testing material fire resistance. Some of the most prominent organizations include the National Fire Protection Association, British Standard Group and FM Approvals.

2.6.1 Who Makes Them?

There are many organizations that create standardized tests. Some of the most well-known agencies are the National Fire Protection Association (NFPA), British Standard Institution Group (BSI Group) and FM Approvals.

The NFPA was founded in 1896. The NFPA deals only with fire protection, hence the name. The process in order to develop a standard begins with public input and then public comment stage. (Cavanaugh, n.d.) The NFPA then has a technical meeting to discuss the inputs and a council appeals and finishes the creation of the standard (NFPA, n.d.).

The BSI Group was founded in 1901. The BSI Group provides a multitude of services. For example, in 1951, a council was created under the BSI Group to begin setting additional standards for consumer goods. When it comes to engineering tests, the BSI Group manages the British Standard which creates tests for many engineering industries (Institution of Civil Engineers, n.d.).

FM Approvals is an insurance company branch of FM Global. They deal with the property damage and prevention aspect of fires, but also produce standards of their own. FM Approvals was founded in 1886 (FM Approvals, n.d.).

2.6.2 Testing Standards

There are many testing standards. A well-known standard is NFPA 285. NFPA 285 is a test initially created by the IBC in 1998. (Hirschler, 2020) The test is conducted by building a 2-story assembly as it would be installed on the building and simulate a fire burning through an open window. The test asses the fire resistance of the assembly in both vertical and lateral directions. (Verzoni, 2017) When a test is completed, the material is then evaluated on every failure condition. If any of the following occurs, the material fails the test:

1. The temperature reaches more than 1000 degrees Fahrenheit 10 feet above the window
2. Flames burning the façade material 10 feet above the window
3. Flames burning the façade material 5 lateral feet from the center of the window
4. Observed temperature above 750 degrees Fahrenheit located in any combustible material at least a quarter of an inch thick.
5. A cavity wall temperature greater than 1000 degrees Fahrenheit
6. A recorded temperature of greater than 500 degrees Fahrenheit 1 in from the interior surface on the second story room
7. Flames observed within the second story room (Valiulis, 2015)

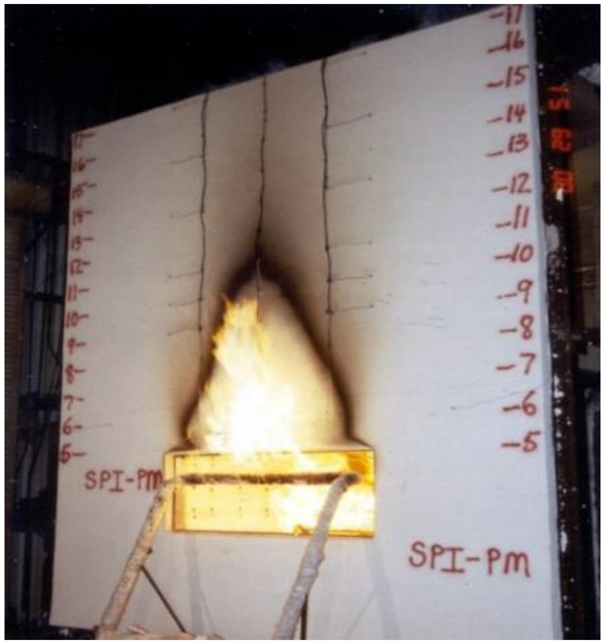


Figure 11: NFPA 285 test being conducted at Jensen Hughes.

(Jensen Hughes, n.d.)

Another well-known test is FM 4880. This test was created by FM Global, an insurance company. The test was finalized in 2007. Before 2007, it was preferred to use the 25 and 50-foot corner tests. After 2007, the 16-foot parallel panel test (PPT) was used as a replacement. The test is conducted by fabricating two sheets of the material of choice, both 16 feet tall (4.9 m) and mounting them 21 inches apart (0.53 m), as well as structural bracing.

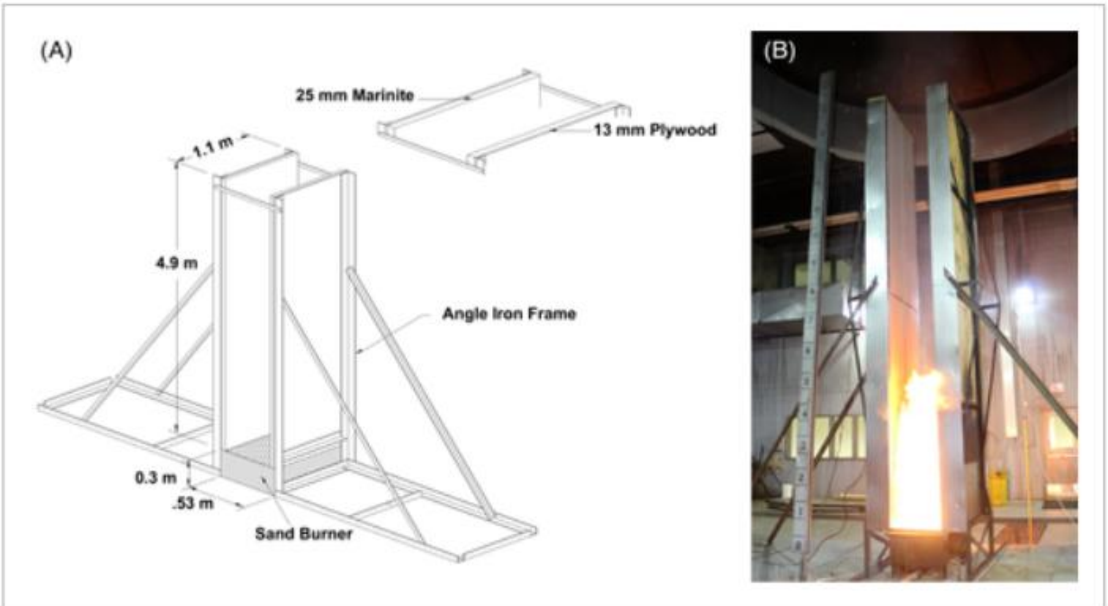


Figure 12: FM 4880 with the 16-foot PPT

(FM Global, n.d.)

The test is conducted by using a burner with a heat release rate (HRR) of 360 kW and a peak heat flux of kW/ m^2. The burner is situated between the parallel panels. In order for a panel to pass FM 4880, the peak HRR is under 1100 kW (Angarwal & et al., 2020).

On the other side of the Atlantic is the BS 8414 test. There are two tests under BS 8414 called: BS 8414-1 and BS 8414-2. BS 8414-1 involves a brick or concrete structural component that the cladding attaches to. This is to simulate buildings whose exterior received a renovation. BS 8414-2 involves more modern building techniques using steel frames where the cladding is mounted onto. Both tests are in the form of a corner wall like that of FM 4880 before the 16-foot PPT. The height of tests BS 8414-1 and –2 is between 26’3’ and 29’6” (8 to 9 m). The failure condition of both tests is if the temperature reaches above 750 degrees Fahrenheit (400 degrees Celsius) (Schulz & at al. 2020).

3. Methodology

3.1 Objectives

ACP (Aluminum Composite Panel) is widely used as cladding in buildings and structures of all shapes and sizes but using it incorrectly can cause unnecessary fire hazards. Determining the risks and benefits of ACP and establishing public and professional opinions on it is key to determining how this material should be used in the future. Different properties of ACP must be considered when determining if it should be used or not and be compared to other materials to find which is the safest and most efficient material for the situation. Professionals involved with these buildings and materials should be consulted in order to get a better understanding of how ACP and other façade materials functions in the real world. The following sections will explain our methodologies and how we attempt to reach our objectives.

We will also be working in conjunction with students from the American University of Sharjah (AUS). Their assistance will be especially helpful for contacts we have in the UAE as it could help us to avoid both a language barrier and time-zone differences for interviews. They will also help us with our research in the material and developing our process towards our final goal.

3.2 Secondary Analysis

Secondary analysis of various fire codes and standards will be one way for us to determine the safety of many high-rise buildings. By studying the development, usage, and evolutions of these codes and standards we will be able to build an understanding of how façade fire safety is viewed in the professional realm. These tests and standards allow us to understand how the physical and chemical properties of these materials are involved in real world scenarios and can give us insights on flame propagation, how the materials interact with one another, and techniques for extinguishing these fires.

Research on the benefits of ACP will also be conducted. It is known that ACP is widely used for its aesthetics, energy efficiency, ease of maintenance, and resistance to weather. This will help us to determine in what scenarios it can be used safely and effectively. Both policies developed by different nations and properties of the material will help us to understand the effect that it can have on different structures and the general public's view of it.

Finally, we will be doing analyses on case studies of high-rise buildings that have had ACP related fires. We will have a primary focus on the Grenfell tower fire as this is one of the cases that is most studied and has a professional inquiry on it. It was also a major landmark case which brought the safety of ACP usage into discussion in the professional world. Other fires such as the torch tower fire in Dubai and the Lacrosse Building Fire in Melbourne, Australia will be investigated and compared with one another.

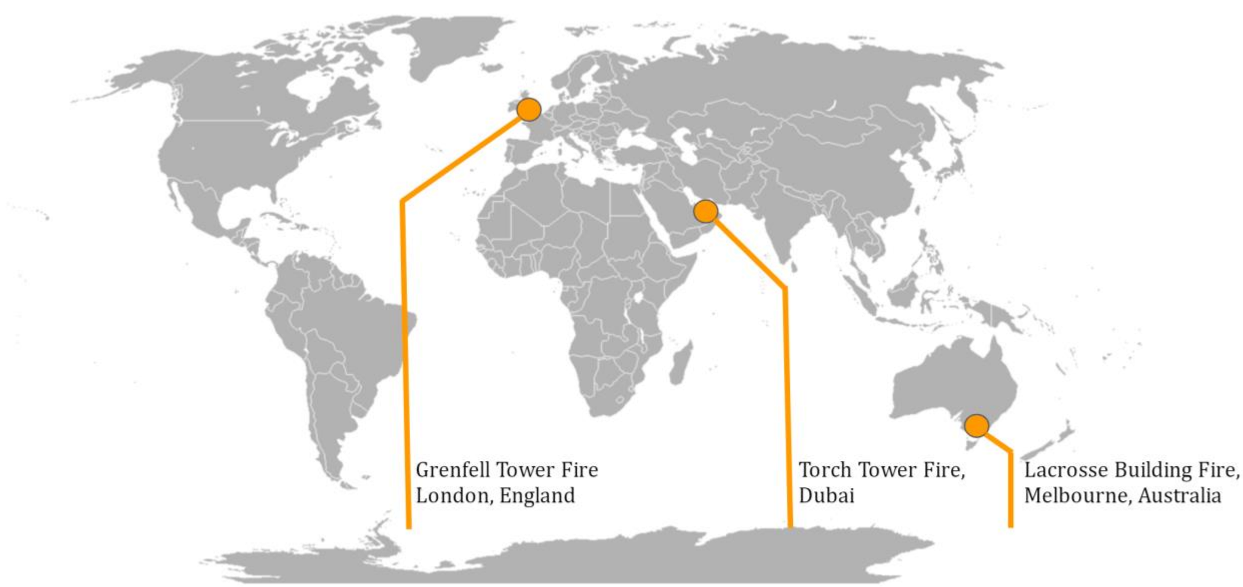


Figure 13: Locations of Key ACP Related Fires
(Presutti, 2020)

3.3 Grounded Theory

For our initial set of expert interviews, we intend to use grounded theory. The idea behind grounded theory is to build up a finalized and definite theory throughout your interviews. We intend to use this for experts in the fields of building facades and fire protection as well as professionals in the fire safety and building material industry. We define experts as people who have had experience with ACP and other facade materials for several years and have developed an understanding of its usage and properties. We defined professionals as people who have worked with developing, testing, and working with building facades as a profession for multiple years and understand what must go into owning, maintaining, and/or constructing these buildings. Although our project focuses on worldwide applications of ACP, we will be conducting interviews with both local experts and professionals in the New England area, as well as those in the United Arab Emirates. Our reasoning for this is that most of our data comes from UAE labs and we have connections around the New England area thanks to advisors and professors. The students at AUS will also be assisting with the interviews in the UAE as a way to avoid a potential language barrier as well as account for the time zone difference between the UAE and the USA. An interview is scheduled in the beginning and depending on their responses to the questions asked we will develop a new theory which involves the new information we have collected. This process works in a cycle and is expressed in the following diagram:

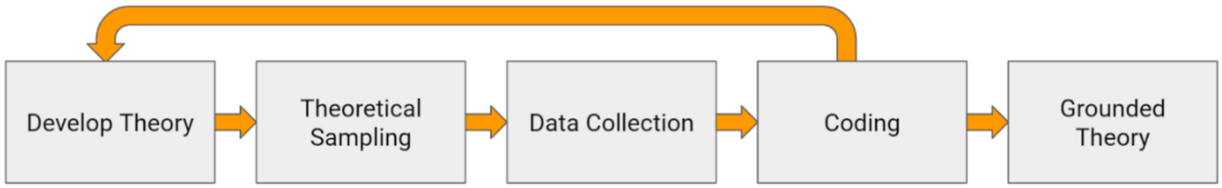


Figure 14: Diagram showing the Grounded Theory process
(Presutti, 2020)

We will begin by developing a starting theory that will help us to determine the questions we will ask and how the interview will be conducted. In this case our beginning theory is as follows:

“Aluminum Composite Paneling is a useful material that can help benefit energy efficiency, ease of maintenance, and aesthetics but can be a major fire safety hazard when used in high-rise buildings.”

Our interviews will begin with professionals who have a broad understanding of fire protection and fire safety standards. For this we will be consulting a fire protection engineering professor from WPI to give us a basis for our interviews. We will ask a series of general questions regarding both the usage of ACP and other facade materials as well as their thoughts on the fire codes and tests that are commonly used. From this we can get a basic understanding of how ACP is viewed by professionals in the fire safety and protection fields

The next step is to take the data from the interview and see how it complies with or goes against our theory. If we view anything similar, it stays in our original theory. If what the interviewee says goes against it, we see how we can change the theory to reflect their views. Any new information will also be coded, and additions will be added onto our theory as deemed necessary. Once this new theory is developed, we pick our next individual to be interviewed.

This process is repeated indefinitely until we believe we have a defined theory that will be the conclusion to this portion of our research.

3.3.1 Choosing the Participants

As previously mentioned, for this we are going to be reaching out to experts and professionals in various fields related to our topic. We intend to choose 5-10 participants in order to get an accurate perception of ACP in the professional world. We will do our own research into who matches these criteria by looking up building histories, companies that work with aluminum composite paneling, and research of professionals in the fire protection field and will pick our participants based upon that. One of the major qualifications for these participants is ability to discuss topics related to ACP and other building facade materials in a reasonable time span, as well as ease of communication. For this reason, we will be picking local professionals from WPI and surrounding areas as well as professionals and experts from the UAE. Our participants will consist of the following: Fire Protection Engineering and Civil Engineering Professors, representatives from insurance companies, fire protection technicians, and people who have experienced high-rise fires involving ACP firsthand.

When discussing ACP with Fire Protection Engineering and Civil Engineering professors, the fire safety risks can be adequately measured. These are professionals and experts in fire safety that have very good insight for the risks associated with the material and could provide possibilities for making it safer to use. Their experience not only with their specialties but with the general field of fire protection will allow us to gain a broad perception of the directions we will be able to go in for our next interviews. Their experience with building codes and how different materials function with one another will also be able to allow us to gain a better understanding of high-rise buildings in general, allowing for us to learn more about how building owners, designers, and occupants view these safety standards.

We will be conducting interviews with technicians at FM Global, an insurance company who also focuses on fire safety testing. This interview will not only give us insights on how insurance companies view fire safety on high-rise facades, but we will also get direct information from people who have conducted the tests and have hands-on experience with these materials. The firsthand experiences and deep understandings of the various tests used in the fire safety realm will give us insights as to how these tests are developed and give us a deeper view into how professionals develop, view, and adapt them.

We will also be interviewing technicians who work with ACP and other façade materials. Their understanding of the research and development that go into these panels will give us an in depth, technical view of façade materials. With this we can gain an understanding of the scientific side of fire safety and apply that to the social aspects which we are studying. These interviews will also give us an insight into how other materials are viewed by technicians and we can ask about how the physical and chemical properties compare.

For those who have experienced fires involving ACP, we intend to ask them about their opinions on the cladding both before and after the event as well as their experiences regarding the fire. Their input will allow us to see a different point of view of these claddings and get the public's experience of it first-hand. Their safety and privacy will be ensured, and we will give them a brief overview of topics we will be covering as well as giving them the option to not answer any of our questions if they feel it is too emotionally straining.

Privacy is also a primary concern in this area, and we will take necessary precautions to ensure the privacy of our participants. For those sampled, the names of each participant will be matched with a number, and this matching will be kept in a password-protected document. The number will match the transcript and any data we are given during the interview, and the participants' real names and locations will be hidden.

3.3.2 Question Development

Before each interview we will be developing an outline of questions we will be asking. These questions will be crafted by our team based upon our background knowledge of the project, an understanding of who we are interviewing and what field they are in, and suggestions made by our project advisor. The primary method of these interviews is to ask follow-up questions based upon the previous answers that have been given by the interviewees.

Our goal for these interview questions is to give us insight into how these materials are viewed by professionals and experts, as they can give us unique insights into these problems that can give us different information than academic papers and case studies.

3.4 Coding of Data

After we finish our secondary analysis and our interviews, we will be coding all of our data onto a continuum with one end being technical data and the other end being social data. The data will be split into six separate sections that we feel covers all aspects of our research: cladding materials, testing standards, fire scenarios, fire safety, public portrayal, and societal problems.

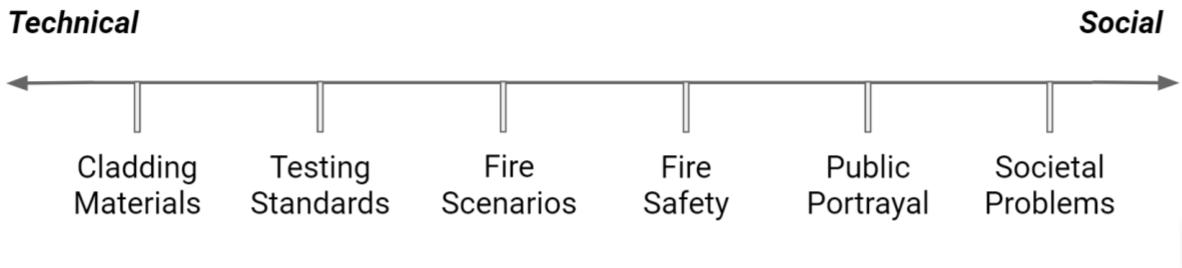


Figure 15: Continuum displaying our coding organization
(Presutti, 2020)

The purpose of choosing these themes for our coding is to allow us to have a broad idea of what goes into making, testing, and choosing these materials. To understand the social aspects of ACP, we must first understand the technical aspects. Knowing what materials are used, how they are tested and approved, and understanding the different types of fire scenarios give us this information. Once this is understood, we can draw conclusions and apply them to our understanding of fire safety in the world, see how it affects public portrayal of these façade fires, and give us more information to delve deeper into the societal and ethical problems posed in the real world by these materials and fires.

Thematic coding will be done on the interviews and the secondary analysis to help us categorize each section. The data we collect will then be broken down into more parts and themes as deemed necessary by our findings.

4. Findings

This chapter details the various findings that resulted from research and conducting expert interviews. The interview transcripts were scanned for insightful quotes and were thematically coded. With this initial coding, different common categories were placed along a coding continuum in which engineering/scientific topics start on the left and social/ethical issues start on the right. Topics are placed along the continuum and topics with an overlap between the two subject areas are placed closer to the middle.

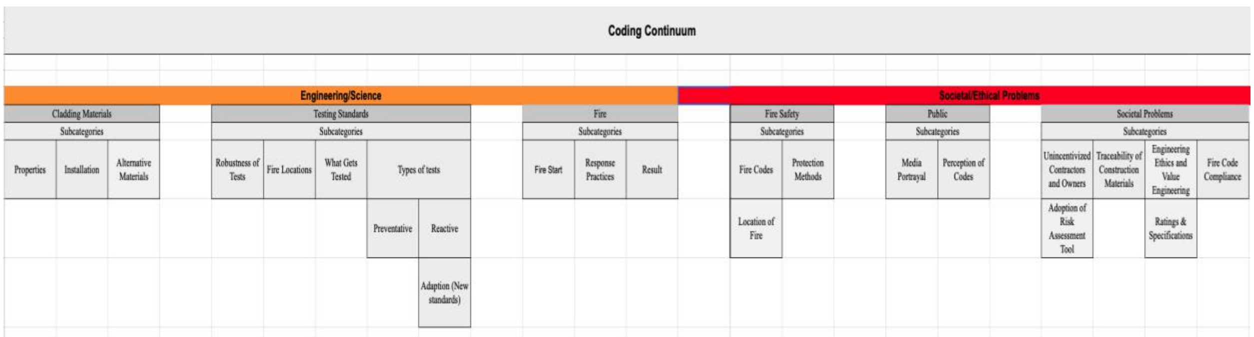


Figure 16: Coding Continuum used for qualitative data
(Yip, 2020)

4.1 Material Properties

From the interviews conducted, we had additional findings on the material properties of ACP. Perhaps the most useful property of the paneling is its versatility. Coming in all shapes, colors, and thicknesses, it is also very easy to cut and shape on the workplace itself. We already knew that low density polyethylene cores in the paneling were the lowest performing, but after multiple fires where it has been involved, countries have begun outlawing its usage as a building cladding as told by an experienced fire testing lab technician: “The lowest performing end of (the ACP core) is low density polyethylene. And the higher performing end of that is more mineral core style, so I've seen a broad range overtime. That range has definitely improved, especially because the performance criteria has improved and because the government has outlawed low density polyethylene." While the low-density polyethylene has been losing favor in the construction world, the newer forms have begun being used more widely. The mineral core forms of ACP are just as versatile as the older forms but have a lower fire risk associated with them.

Although it can sometimes be marketed as an insulating material due to its polyethylene core, it does not pose much composition to other potential facade materials such as EIFS. The potential to use it as an insulator is present when the facade system is designed around the ACP functioning as an insulator with increased wall gaps. These gaps enhance the stack effect within the walls of the facade and can be used to supplement the building's insulation. This stack effect also causes air to disperse more rapidly in the case of a fire resulting in a much faster propagation of the fire.

4.1.2 Installation

From the expert interviews, it was suggested that the safety of ACP (Aluminum Composite Paneling) usage depends on the installation and implementation methods in close conjunction with other adequate preventative safety measures. One of the issues brought up in the background and in the interviews was the presence of an air gap between the paneling and the structural wall on buildings.

In reference to the Grenfell Tower fire, a material scientist and professor stated: "If it's used properly, sure. You know, in cases like the Grenfell Tower part of the problem was that there was an air gap between the cladding in the building, and so it was like a charcoal like starter chimney. You know if you've ever had to light a grill where if that air hadn't been there, the one apartment where the fire started probably would have burned but not."

However, there isn't a consensus on what size of an air gap is worse. An expert working at a fire safety certification company stated in an interview that the biggest cavity to be used in the entire building is tested and if it passes, they assume all other smaller cavities will as well. On the other hand, another expert expressed uncertainty in whether big or small cavities worsen the propagation of fire as a result of the chimney effect. Considering all the possibilities, there is room for improvement in both fire science and the development of new materials.

4.1.3 Alternative Materials

In conducting both expert interviews and research, the potential for alternative materials arose. Some of the materials that could be used in place of ACP include glass, mineral wool insulation, and solid aluminum. Other materials include stainless steel, External Insulation Finishing Systems, Glass Reinforced Fiber, concrete, composite tiles (which are similar to ceramics) and marble. In addition to full substitutes for ACP, different types of more flame-resistant ACP (A2) as well as panels with different types of cores have been used. One of the experts highlighted a full stainless-steel panel with honeycomb interior which featured the same thermal properties throughout. Innovative materials like the aforementioned stainless steel in addition to proven materials/systems like solid aluminum and EIFS highlight the number of options available to the industry.

It is possible to meet demands such as aesthetics and energy efficiency with other materials, cost remains a potential concern. Ultimately, regardless of cost, alternative materials must serve a similar intended purpose and prove to be less of a safety risk when compared to the ACP it aims to replace. While many of the materials can be viewed as "proven", it is imperative that they be subjected to same scrutiny as ACP and held to testing standards to minimize risk and maximize safety performance.

4.2 Testing Standards

Testing standards are a key means in helping to create safer products and buildings. In conducting both research and interviews, further insight into the formation and application of testing standards was gained. Testing can be done both proactively (preventative) and retroactively (reactive). Both forms of testing are incredibly valuable with respect to public safety and are useful under different circumstances.

4.2.1 What Gets Tested?

There are an abundance of materials, components, and assemblies, that are subjected to testing before they are approved for use on buildings. The tests that are performed are part of a process that enforces standards created by agencies such as the NFPA or insurance/risk assessment firms such as FM Approvals. From one of the interviewees, who works for an insurance company, said they are more concerned about the damage to all aspects of the building, exterior or interior. As an insurer, they pay for property damage for fires. Because of this, they have produced their own standards that get tested materials.

4.2.2 Preventative Testing

From one of our interviews, we gathered that there are two types of testing, preventative and reactive testing. The process of preventative testing is where a material or assembly is evaluated to a certain standard before it is approved for placement on a building. This form of testing also includes attempting to anticipate changes in the building industry and modifying or creating new standards accordingly. While preventative testing is used to certify materials or assemblies, it can only verify based off of the conditions within the testing lab. Errors in construction or substituted materials cannot be controlled from a testing perspective.

4.2.3 Reactive Testing

Reactive testing is the practice of modifying or adding standards based on an event or trend in the building industry. For example, one of the interviewees didn't have a standard dealing with cavity wall fires. When the Grenfell Tower happened, fire protection agencies had to respond to the fire and add testing standards. In comparison to preventative testing, reactive testing is a more complicated process. This ties in with issues of material traceability as well as material properties. In order for tests to be properly conducted, the material sample must be in an "as delivered" condition. For this testing to occur, the exact manufacturer and variety of panel must be known. Additionally, a brand-new sample may behave differently than a weathered panel that had been installed for a period of time. While these potential hurdles may exist, reactive testing remains as important a process as preventative testing.

4.2.4 Robustness of Tests

One of the issues an interviewee brought up is how do architects and engineers know which material to use for their facade based on the tests that each material passed? Each material has to be tested and have its specifications verified in order to be a listed material. That process starts with the material being tested by an agency. The test could be NFPA 285, tests from FM or other agencies. Once the material passes the test, a third party looks at the specifications of the material. In the words of the interviewee, "they are looking at the specifications of like materials and it gets 'added to a list'". A design or test number is attached to the material, so people can access the tests it passed and the certifications of the material.

4.3 Fire

Fire is seen as a force that has long threatened human settlement throughout history. In each major fire there is a cause, a response, and the ensuing aftermath. As a result of major fires, the field of fire safety and the need for fire codes/regulations has come to light. This section details the findings made in the study with respect to the social and scientific aspects of fire.

4.3.1 Cause of Fire

From one of the interviewees, we heard about the experience of being in a high-rise fire. The building which the fire happened was The Torch Tower in Dubai. It is known the of the building is fitted with ACP. The fire itself was caused by people smoking and throwing the ignited material onto a lower balcony. The balcony caught fire, spread to the cladding and the fire escalated from there.

Regardless of the severity of a given fire, one common factor is that each had an ignition source. The start of a fire is often the key factor which comes under much scrutiny following an incident. In the case of the Torch tower, an interviewee had indicated that the initial cause of one of the fires was a shisha smoking device located on a higher-level balcony. The ordinarily small flame on the device burned out of control due to high wind and fell onto the floor prior to catching flammable balcony objects ablaze which eventually spread to the cladding. This seemingly small ignition source compounded with a lack of external sprinklers and flammable cladding was enough to cause the side of the Torch Tower to be engulfed in flames. This served as a lesson in where, with the right conditions, a seemingly small ignition source can become a major issue.

4.3.2 Fire Response Practices

A degree of the outcome of a fire can be influenced by the dispatch of emergency responders and the protocol they are to follow. From our interviews and research, we found many different methods of response. For instance, in the UK, the fire department orders people to stay in their apartment. This practice is common in the United Kingdom because they build their apartments to be compartments and not let the fire spread outside the apartment of origin. This is part of the reason why Grenfell was so deadly, lots of people stayed in place and the fire made its way up their floor via the cladding. From the interview with someone who lived through two façade fires, they noted the fire department would often break through the apartment in order to fight the fire.

4.3.3 Results

Through interviewing someone who was a part of both Torch Building fires, we gained the knowledge of aftermath caused by fires. One of the major points brought up about residents after the fact was, they became scared of living in them. Residents were unsure if their building was one that could light up like a roman candle or be fire resistant. With ACP, the same could be said. The wide range in fire resistance properties means a building fire that reaches the cladding could either scale the entire building or slow the progress, as a rather extreme example. The fact that the Torch Tower had two separate incidents was enough for the interviewee to not want to live in a high-rise again, regardless of the cladding material.

When asked if they would live in another high-rise again, they answered: “Of course not. I mean now I moved to a house. So, one of the lesson[s] then I would never live in a tower. If I can, I will avoid [it].” There are certainly more people who hold this same view.

Following the large amount of physical damage from the fire, a number of legal cases ensued. Numerous apartments affected by the were not covered under home insurance. As a result, there are ongoing lawsuits centered around who is to blame. Those without insurance could not receive compensation and could not return to their apartments. The amount of legal cases resulted in an increase in home insurance purchases in the area.

At the intersection of science and

4.4 Fire Safety

In technical aspect of fire safety, it is one of the first lines of defense against a large-scale fire. What systems should be put in place to prevent fires from spreading? What materials are permitted to be installed? How can those materials be installed to ensure public safety? And lastly, what systems can be put in place to allow for a safe evacuation? These are the basic questions overarching in fire protection engineering.

4.4.1 Testing Standards

From our interviews, we gained the knowledge of new codes and standards as well as new perspectives of previous ones. One of the standards found during the interview process was FM 4411. FM 4411 is a relatively new standard. It was created in 2018 as a response to the numerous high-rise façade fires around the world. The standard measures flame propagation while considering cavity walls present between the cladding and structural components.

Figure 17: An image of test FM 4411 being conducted (32)

The image above shows an FM 4411 test being conducted. An eight-foot wall is constructed with a cavity. For air gaps 1-2" in the installed assembly, test the assembly with a 2” gap. For 2-4", use a 4” gap. In order to conduct the fire portion of the test, a propane sand burner with heat flux to sample surface measured 6” above burner of 40-45 kW/m². This burner will heat the materials around the air gap for 15 minutes. The amount of heat a burner releases for each cavity width is 5.8 kW or 4.2 L/min for a 2” gap and 9.5 kW or 6.8 L/min for a 4” gap. To measure the heat release from the assembly, a 5-MW calorimeter is used. In order to pass the test, the assembly must release less than 100 kW and have a maximum flame height under six feet tall. One extra note is that EIFS cladding or other exterior wall coating systems are not meant for FM 4411.

As a result of the interviews, we gained more insight on testing standards we previously discussed in the background. One of the tests is NFPA 285. What we didn’t know about NFPA

285 was that it is a test at the forefront of the industry and a key benchmark for how fire resistant a material is.

4.4.1.1 Location of Fire

One aspect of fire safety is where the fire spreads to and the perception of what safety measures need to be in place to mitigate the risk. For a while, fires were perceived as a threat to the interior of the building. This is partially because exteriors were made of non-combustible materials. With building's now being fitted with combustible materials, it caused the industry to have to react to the changes and create standards that reflected them. This quote from an interview further enforces this idea: "You have probably heard it from [another interviewee] so much of building fire safety, structural fire safety is based on an interior fire. Yep, and so now [you're] looking at something from the exterior."

4.4.2 Fire Codes

From our interviews, we found the importance of many fire protection methods, but also how they differ between countries. For example, in Singapore, they do not use sprinklers as the materials they use are not combustible. This is in heavy contrast to the United States, where sprinklers are used abundantly, and cladding can be combustible up to 40 feet above grade as stated before. This shows a clear difference in fire protection mentality. Singaporeans believe their materials will stop of the spread of fire by being fire resistant, while Americans believe sprinklers will stop the spread the fire.

In the UK, the mentality is similar that of Singapore. In apartments, they use non-combustible materials and specifically try to keep the fire from spreading beyond the apartment of origin. A quote directly from one of the interviews: "So, so that's the that that was the policy in the UK. But that's on the assumption that the fire hasn't spread beyond the apartment of origin.

So, if there's a fire in a fridge and it stays in the apartments, then everyone else should be quite safe cause they're all in their "one-hour boxes" … Their own apartments, and the materials of construction are not combustible, so it's not going to spread to other apartments or other floors."

To stop the spread of fire up cladding, the continuous façade can be broken up by fire stops or balconies, for example. With fire stops the chimney effect in cavity walls can be mitigated by compartmentalizing the gaps. One of the interviewees we talked to described a risk assessment tool they helped develop. The tool categorized buildings based on the components they had installed. If the building had combustible cladding or the lack of sprinklers, for example, it would rank higher.

"So, if there was a sprinkler building, we assume the risk of the fire breaking out into the facade was say low versus, if It was a non-sprinkler building, the risk of a fire breaking out into the facade was high." This shows the importance of installing sprinklers in high-rise buildings. For staircases, there was a little uncertainty surrounding them. Some experts said that an extra fire rated staircase wouldn't be critical reason why the Grenfell Tower caused many deaths because of the speed the fire spread at. Other experts noted that an extra staircase could have made the egress process quicker and more orderly.

Building and fire codes with regard to renovated buildings in several jurisdictions do not require latest code compliance if the cost of renovation does not exceed a certain percentage of the building's value. This potentially flawed approach can give the average resident a false sense of security that comes with a building that appears new. An any instance, the ununiform application of codes is reason for concern.

4.5 Public Response

Fires and other large-scale disasters have captivated the attention of the general public for ages. In nearly every incident there are people directly affected, bystanders, and those yearning to learn about those experiences. Through means such as word of mouth, mass media and the internet, opinions and responses on these fires and regulations spread throughout the world. It is important to consider these responses in order to gain perspective into the social aspects attributed with fires.

4.5.1 Media Portrayal

While a percentage of individuals have not experienced fires for themselves, their perception of the situation is deeply shaped by media coverage. As learned from expert interviews, the true cause of the severity of the Grenfell Tower was much more in depth than originally reported. The media and its portrayal of fires and their causes are generally factual to some degree. However, the nature and pace of news reporting runs contrary to methodical investigation methods practiced by forensic engineers and expert testimony. While an official investigation aims to catalog every detail, the media must report events as they happen which often involves initial guesses and relying on first-hand accounts as information becomes available. The media by no means specializes in engineering or technical topics though some sources may attempt to gain professional insight. In an interview, it was mentioned that some news outlets will attempt to contact professors, engineers, or industry professionals to obtain an opinion. Though, as a part of good engineering practice, such requests are often not granted as there is insufficient information to make an informed judgement. Since professionally informed judgement is not always available, the blame can tend to be misplaced by the media. This view of an incident is typically what is easily accessible to the general public and will shape their understanding. Referring to the Grenfell example, our interviews had mentioned insufficient fire safety measures and flawed protocols based off assumptions that proved incorrect. While the media can often bring a sensationalized and incomplete view of a problem, it does succeed in bringing the incidents to the eyes of the public. Due to this, the media plays a powerful role in informing the public of incidents and potentially starting a dialogue in which, the general public rethinks topics related to safety.

4.5.2 Perception of Codes

Fire Codes and Building Codes imposed by an AHJ (Authority Holding Jurisdiction) ultimately impact the safety of those that reside within those areas. However, the intentions and the means of which the codes are written and enforced can lead to public contention. The public can either feel the codes in place are too strict or not strict enough, depending on personal experience. Others see the codes as a burden, which imposes additional costs to them.

As explained by a professor of civil engineering: “I’m saying to myself, it's like putting the building code as this big demon that's in the way versus I think it's a whole question of our public policy, right?”

To the average person, fire and building codes seem like arbitrary restrictions on what goes where or how many people are allowed in a room. While they could be frustrating, the devastation following a fire would far outweigh any inconveniences attributed with compliance. While fire codes are meant to protect the public, the public’s education on the subject can be seen as generally lacking which fuels misunderstandings. Large amounts of municipal building codes are dedicated to fire, which can be daunting to try and understand. Members of the general public might see no reason to understand it, while engineers and other professionals may be tempted to treat it as a dull task.

Seeing codes as a burden rather than an important piece of safety guidance can lead to the mentality of relegating code compliance to being a “checklist task”. A professor’s account of a colleague’s lesson vividly illustrated the faults of this mindset. “Oftentimes with senior project groups, he would say we're going to design a code compliant building, but it's going to be a death-trap. Basically, he would show them how there's certain parts of the code that if you put things together in a way that follows what is said as a checklist from a design point of view, it's not the best solution.” From this anecdote and other bits of experience gained, it could be gathered that the sense of risk attributed with fire and other types of tragedy appear as a remote “off chance” to a number of different groups of people. While it isn’t necessary to live in complete fear, a degree of respect of the danger and unpredictability is in order.

4.6 Societal Problems

While certain aspects attributed to the outcomes of fires such as the propagation of flames or the rating of fire-resistant materials fall under the realm of science and engineering, ultimately the impact of fires and some of the reasons that fires start can be traced back to society. These problems impact society as well as the interest of global public safety.

4.6.1 Un-incentivized Buildings Owners and Contractors

One of the interviewees we talked to uses a risk assessment tool to find which buildings of clients are at the highest risk of a devastating building facade fire. We asked them if building owners are willing to use the tool. They said it is about the owner’s reputation and if they are financially ready to invest in their building’s renovations. If building owners do not have the cash to renovate their buildings, they’ll be less apt to use the risk assessment tool. This is because owners wouldn’t want their insurance companies or tenants to know their buildings are at higher risk of fire. They also explained that sometimes owners go out of their way to use the risk assessment tool because insurance premiums are raised on the owners.

From the interviews, we learned that the larger and higher profile firms would be more open to utilizing various means of risk assessment. These types of firms or individuals have a lofty reputation which they aim to preserve. To them, investing in managing/reducing risk is worth the tradeoff. Typically, those would already consult with insurance or risk assessment firms like FM Approvals. In that scenario, there is less likelihood of a pushback to recommendations or changes.

A potential area where building owners and contractors may be particularly un-incentivized is with regard to existing buildings or systems which may have been "grandfathered in". The existing systems could be less effective or efficient when compared to newer systems, but meeting current standards is deemed cost prohibitive. In different jurisdictions around the world there may be no such requirement to meet current standards, thus owners take the "business as usual approach". This approach initially saves the owners/contractors money but hinges dangerously on the assumption that existing systems/standards perform as effectively as when they were implemented. When combined with other variables, this opens the door for potential tragedy.

4.6.2 Material Traceability

In order to facilitate proper installation of tested materials and to allow for retroactive tests, materials must be easily traceable. Traceability is also a question of accountability and proper material management. Improper or insufficient labeling can lead to the installation of lesser-performing materials or substitutions to be made during the building construction. This would be particularly concerning matter if a material type of material were recalled. In the case of ACP, it could be difficult to know what exact kind of ACP was installed without proper documentation. In addition, the wide range of fire properties of ACP means paneling installed could either be very flammable or fire resistant.

During an interview, a testing technician likened the situation to the response following the San Francisco earthquake in 1989. In that case, the problem was building foundations that were not up to the most recent iteration of the building code and were at risk of failing in a future earthquake. Drawing a parallel with the issue with ACP, there were numerous buildings in the area with non-compliant foundations and there was effectively no way to quickly find out which ones. As a result, a city-wide survey was conducted in order to determine which buildings were in need of retrofitting. In that example and also with ACP, material traceability would have made the process less time intensive which is important when dealing with uncertainties such as when disaster may strike.

4.6.3 Ethics and the Pitfalls of Value Engineering

Ethics come into play whenever a decision is made in the process that begins when a building is designed through to its continued usage. A careful balance must be struck between aiming to reduce costs and following professional ethics such as those that engineers are urged to follow. Aside from potentially wanting to cut costs on a project for the sake of profit, pressure also arises from the pressure of keeping to a budget. During an interview with a professor of civil engineering this explanation arose:

“Oftentimes people say low-hanging fruit, go after the low-hanging fruit, right? Because they've got a project that's over budget and they look at things that they can change at a late date. Maybe much of the structure has already been placed … so you can't really do much with the whole redesign. But you look at where you can make changes … as the engineer, you're supposed to hold public safety paramount and so then it becomes a question of assessment of the risk versus the expectations to try and reduce cost.”

The practice of reducing project costs is referred to as “value engineering”. While finding solutions that result in cost savings isn’t inherently dangerous, losing sight of both details as well as the bigger vision of a project can be dangerous. An interview with a professional engineer and professor cited case studies such as the Kansas City Hyatt Regency walkway collapse where a seemingly minor detail was changed to allow for cost savings and easier construction. In changing the design, a fundamental principle was overlooked in the interest of cost/time savings. The same type of potentially fatal error can be made with regards to both ACP installation and fire safety as a whole.

An interview with a fire protection professional, it was discussed that buildings in some jurisdictions are not required to meet the latest fire safety or building codes if the remodeling of a building that purposely does not exceed a set percentage of a building’s valuation. This practice is of concern from a safety standpoint, due to parallels to the Grenfell Tower renovation where some systems were updated but others were not required to be. This has the potential to create a dangerous environment. If a professional such as an engineer becomes aware of an unsafe situation, whether caused by value engineering or not, it is imperative to bring it to attention. Such a responsibility was explained in an interview. “Ultimately, as a PE, if you're going down a path that you know you're totally unacceptable with, you know it's incumbent upon you to state your case, and if necessarily have to become your own whistle blower.” The primary example of “whistleblowing” was the case study of the Citicorp Tower, in which the structural engineer alerted the owner of a structural flaw and arranged for it to be properly corrected. In the case of fire safety, it would be important for individuals involved in the safety plan or systems of a building to regularly assess the serviceability and usability of said systems. If someone for example notices a blocked escape stairwell or damaged safety equipment, a note should be made and corrected rather than wait for the next safety inspection. When safety is in the balance, ethical behavior is key.

4.6.4 Fire Code Compliance

A critical component in way society handles the protection of the general public is with fire codes which are typically set-in place by an authoritative body. There are numerous aspects of fire code compliance. The routine inspection of the building and testing of fire safety systems is perhaps the key aspect.

One of the major issues with the Grenfell Tower fire was there were a lack of sprinklers protecting against a fire. Couple this with inadequate smoke alarms and combustible cladding makes for what an interviewee called “a perfect storm”. This is due to insufficient inspection of buildings. The fire might not have spread beyond the apartment of origin had it been for the addition of sprinklers. Furthermore, having more smoke detectors would have warned residents further away from the fire of the hazard and would have more time to evacuate. Therefore, routine inspection as a part of fire code compliance is paramount.

The issuance of fines or instating corrective orders is another component of fire code compliance. This is similar to incentivizing contractors to correctly install the materials onto the building, but instead with owner’s being penalized for not following the safety measures.

5. Conclusion

From our findings, we gathered several takeaways. One of the main takeaways is ACP can be fire resistant if the cores of the material are not flammable. Furthermore, if the material is installed correctly, then the fire resistance of the assembly will increase. Conversely, ACP can be misused and lead to potentially catastrophic fires. Certain types of ACP such as varieties with low density polyethylene cores are particularly flammable and should not be used. The specific applications and ratings of ACP should be considered during the design and construction processes.

ACP, other materials, and assemblies should be regularly tested to meet current and projected safety standards. Preventative testing is a means in which ACP can be audited for compliance ahead of any large orders or installation. Assemblies undergoing testing prior to installation also helps to provide a better understanding of potential hazards during a fire emergency. The establishment and practice of extensive preventative testing standards is a vital component of building fire safety.

The wide variety of ACP available combined with a general lack of material traceability leaves an unacceptable degree of uncertainty of actual cladding assembly properties. Without adequate traceability, there is no guarantee that ACP or any material for that matter is being installed as approved/tested. This degree of uncertainty is what can be the difference between performing as specified and an unacceptable tragedy.

Another key takeaway was that to some architects and engineers, codes are seen as a hinderance and could be treated as items that simply need to be checked off of a list. This is a dangerous practice that does not fully account for maximum public safety. With this mindset in use, it is entirely possible to create code complaint, but extremely hazardous buildings when factors such as human behavior under panic or location of exits are ignored.

With fire codes in mind, the final takeaway is that codes and compliance vary widely across the globe. Different regulatory bodies oversee developing and enforcing codes around the world. While they do vary, there have been prior efforts to standardize or align codes. These efforts have not been fully successful, but it does show that the idea is there and could succeed with the right conditions. The interest of global public safety is paramount and must be embraced worldwide.

6. Recommendations

Based upon the results of our research, secondary analysis, and interviews we have come up with four recommendations to help promote the safe usage of ACP and other building façade materials. The purpose of our recommendations is to ensure adequate fire safety in the development and testing of these materials, as well as in the testing and designing and installations of high-rise facades.

6.1 Halt the use of low-density polyethylene in high-rise façade paneling

One point we found in our research is that most of the major fires occur with ACP which utilizes low density polyethylene (LDPE). This core is extremely combustible when compared to other façade materials and has already had pushback from fire protection officials in multiple countries. To halt the use of this material would mean a decrease in major ACP fires and will allow for more research to go into fire-retardant materials as replacements.

There are multiple other materials that can be used as replacements for LDPE, such as mineral honeycomb cores or newly created A2 panels. These panels would allow all the benefits of ACP, such as the versatile aesthetics, structural durability, and ease of maintenance without being as combustible as the LDPE cores.

Policies can be put in place by local governments to outlaw the use of LDPE and other combustible façade materials to ensure the fire protection in high-rises. Buildings which currently utilize LDPE panels can be allowed either a grace period to replace the panels of multiple years, or be grandfathered into the new laws, depending on what the local authorities would deem fit.

6.2 Establish a way to ensure adequate fire codes are followed throughout the US/globally

The US has had fire codes on a local level throughout its history. There has always been the debate as to whether these sorts of regulations should be established locally or federally. This can act as a benefit however with the varying locations and environments throughout the nation. For the majority of regulations, they are established via the recommendations of the National Fire Protection Agency or the International Fire Code, both being US based organizations. While fire codes will always vary from location to location, there should be a way to establish that all locations are using up to date, adequate fire codes that are being enforced federally. To create a balance of power, the federal government will establish a baseline of fire codes and standards to ensure adequate fire safety for all buildings, such as the outlaw of combustible materials as facades. The states can assign supplementary codes and standards as they deem fit. These supplementary laws can be established due to environmental, cultural, location based, and other concerns

This mindset can be applied worldwide. While the US attempts to keep a balance of power between the federal government and the states, other nations with a more powerful government would have the ability to ensure adequate fire standards throughout the nation. With smaller nations this would be very effective due to the low amount of variance within the borders. These would help allow for safer construction and engineering for existing and future building and high-rises.

6.3 Improve traceability of materials

The traceability of materials was identified as one of the critical areas that required improvement during multiple expert interviews. Materials are ideally tested for compliance with standards prior to being approved for installation. Without the correct types of labeling, it can be difficult to determine if the materials delivered to the construction site match those originally specified. A source of compounding error in this case is the improper installation of the material/assembly on the actual building. When the assemblies and materials installed do not match those that were originally specified and tested, there is the possibility for unexpected results in case of a fire. This element of uncertainty is unacceptable and should be mitigated with a sense of urgency.

The recommended course of action for this problem is to improve accountability and traceability throughout the supply chain and installation process. Starting with the ACP manufacturers, a uniform labeling system should be implemented. Such a system should include key information such as supplier/manufacturer as well as the model, batch number and any applicable ratings/standards. There could also be multiple checks throughout the procurement and construction process. In modern logistics, material passes through so many different facilities and individuals. This is where accountability would play a key role along with proper labeling. Once the ACP has been delivered, it should be verified with specifications and shop drawings if possible. If there is any doubt, the material should be either rejected or submitted for testing. Technology that aids in construction management such as Building Information Modelling (BIM) and digital paperwork management should be employed to help increase knowledge of materials used on the project. Applicable information should be kept on file or passed onto key project stakeholders if possible. The goal would be for project stakeholders and manufacturers to be educated on what materials are being delivered and installed. Record keeping and open channels of communication should be maintained in case of a future recall.

Following this, attention should be paid to the installation processes and ensuring that methods used are both code compliant and match manufacturers guidelines. This overlaps with the next recommendation on encouraging the spread of knowledge in the industry.

6.4 Better incentivize engineers and contractors to be more knowledgeable on ACP and Fire Codes

One major problem that was discovered in our findings were the ethical concerns revolving around the perception of most fire codes and standards. We found in our investigation that there are many engineers, designers, and contractors who view these fire codes more as hinderances than view them as paramount safety concerns for buildings. Many times, fire codes only come as a result of major catastrophes and are more reactive than preventative. It is this sort of carelessness that can cause disasters such as the Grenfell Tower Fire or the Lacrosse Building Fire.

In our findings, we found that some companies, such as the insurance company FM Global, has a focus on ensuring minimal damage done to the building. One way they do this is not only ensuring materials and such are up to code but ensuring that entire assemblies function well in the case of a fire. While the primary concern of this is to be a lucrative business, it gives the right mindset that these codes must be fully understood and sometimes even supplemented to ensure the prevention of major fires.

Raising awareness about the importance of these fire codes and standards could help prevent these catastrophic events from ever occurring and allow for more robust fire safety in high-rises. This can be done by having more communication between insurance companies, testing labs, and engineers and contractors. This can also be established in the education stage of most professionals and supplementing many fire protection engineering and civil engineering classes with the importance of understanding codes and standards. These professionals can also gain a better understanding of the codes in general allowing for them to correctly apply them and prevent any major fires from ever becoming as devastating as before.

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APPENDIX A: INTERVIEW PROTOCOL FOR PROFESSIONALS

Interview Template A

Experts in the field of materials or fire protection will be interviewed using the following questions in order to establish a grounded theory.

Expert Interviews:

- Are you familiar with Aluminum Composite Paneling (ACP) usage in the building industry?
- If so, how are you familiar with it?
- If not, here is a brief synopsis:
    - Aluminum Composite Panels (ACP) are commonly used worldwide as cladding in high-rise facades, but may introduce some fire safety risks.
    - Used due to energy efficiency, ease of maintenance, low cost, and aesthetics. This allows for buildings to offer a higher quality of living for a lower price.
    - Aluminum has a relatively low melting point (660 degrees Celsius)
    - The plastic core can potentially be flammable
    - Some panels use air gaps in conjunction with the insulation which causes a chimney effect which can draw flames higher up onto the facade.

- What do you know about the risks and benefits of ACP?
- How do you think the media portrays ACP?
- What other kinds of building facade materials are you aware of?
- Are you familiar with building fire safety codes?
- How important do you think materials are in fire safety of different buildings?
- What do you believe are the most important factors in high-rise fire safety?
- What do you think some good alternatives to ACP would be?
- Do you think the risks of ACP outweigh the benefits?
    - Should ACP still be used in certain instances?
    - Do you believe that it is a safe paneling to use on buildings?

APPENDIX B: INTERVIEW PROTOCOL FOR INDIVIDUALS INVOLVED IN FIRE

Interview Template B

Experts involved in fires will be interviewed using this template.

Experts who have experienced fires with/without ACP:

- Are you familiar with Aluminum Composite Paneling?
- If not we give them a brief synopsis on it as follows:
    - Aluminum Composite Panels (ACP) are commonly used worldwide as cladding in high-rise facades, but may introduce some fire safety risks.
    - Used due to energy efficiency, ease of maintenance, low cost, and aesthetics. This allows for buildings to offer a higher quality of living for a lower price.
    - Aluminum has a relatively low melting point (660 degrees Celsius)
    - The plastic core can potentially be flammable
    - Some panels use air gaps in conjunction with the insulation which causes a chimney effect which can draw flames higher up onto the facade.

- Which building were you in during the incident?
- What floor were you on?
- What was your involvement with the building before the fire?
- What was your experience of the fire?
- Was the immediate area you were in ever on fire?
    - If so, how much damage was there?
    - What was the rate of spread?
- How long did it take to evacuate?
- Were you able to evacuate efficiently?
- How long after the fire were you able to resume normal activity?
- How long was that compared to other individuals?
- Do you/did you feel safe in the building?

APPENDIX C: INTITUTIONAL REVIEW BOARD INFORMED CONSENT SHEET

Informed Consent Agreement for Participation in a Research Study
Worcester Polytechnic Institute

Primary Investigator: Joseph Doiron

Contact Information: jdoiron@wpi.edu

Title of Research Study: High-Rise Fire Safety

Sponsor: Jensen Hughes

Introduction: You are being asked to participate in a research study where you will be asked to provide your knowledge or prior experiences. The purpose of the study, procedure, benefits, and any potential risks or discomfort associated with participation are outlined as follows. The information presented about the study is to aid in a fully informed decision regarding your participation.

Purpose of the study: The purpose of this study is to gain knowledge on the topic of high-rise fire safety pertaining to the use of Aluminum Composite Panels (ACP). The methods to be used have been designed to collect information from experts and individuals that have had experiences with ACP or subsequent fires.

Procedures to be followed: The research study follows the methods of grounded theory and purposeful sampling. All interviewees will be asked if they are familiar with Aluminum Composite Panels. If they are not, an unbiased synopsis of the material will be given.

Before the expert interviews,an initial theory will be formulated as a premise which individuals will be interviewed based on. Experts will be asked about the theory and some additional questions. Subjects will be asked about the media perception of the material, alternative materials, and if the benefits of ACP outweigh the potential risks. After the first interview is conducted, a new theory would consist of the initial theory and of the first interviewee's opinion. This process of developing a theory and interviewing will repeat.

Individuals who have experienced fires would be asked which building and floor they were in as well as their involvement with the building prior to the fire. They would be followed up on their experiences during the fire and if they were personally affected. If their immediate surroundings were involved in the fire, they would be asked about how much damage there was and approximately how fast the fire spread. If they were evacuated, they will be asked how long it took to exit the building and if they felt it was safe/efficient.
The participants will be asked about their post fire experience if applicable.

Risks to study participants: Steps to minimize risk have been taken, though the elimination of all forms of risk cannot be guaranteed. Strong emotional feelings may be brought up as a result of the interviewing process, though best practices will be implemented in an attempt to avoid discomfort. The participant retains their right to not answer any questions, request that certain topics not be mentioned, and are ensured confidentiality.

Benefits to research participants and others: There are no clear direct benefits to individuals involved in the study, however the data collected may have future positive societal implications in the area of global public safety.

Record keeping and confidentiality: Interviews and associated data throughout this study are to be recorded via audio recording. No transcripts or recordings will be made public or shared without expressed permission of the participants. The full recordings and their transcripts are kept only as a temporary record to be used by personnel conducting the study in order to extract information as part of the previously mentioned grounded theory method. Information obtained through the study will be primarily synthesized to form educated opinions or theories regarding the applications of ACP. However, excerpts or specific quotes may be used on a case-by-case basis with participant permission.
Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: Any injury or harm resulting from this study is highly unlikely. The study is to be conducted online or in-person at a high level of social distancing on a case-by-case basis. As a result, there are no formal provisions for compensation or treatment. Further information or considerations can be addressed by contacting the primary investigator or other personnel attributed to the study.

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For information regarding the rights of research participants or compliance based concerns, refer to the contact information below.

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Human Protection Administrator:
Gabriel Johnson - Tel. 508-831-4989 - Email: gjohnson@wpi.edu

Participation in this research is voluntary. Refusal to participate will not result in any negative implications. You may decide to stop participating in the research at any time without any detriment or associated risks. The project investigators retain the right to cancel or postpone the research methods at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____________________________ Date: ____________________
Study Participant Signature

____
Study Participant Name (Please print)

_____________________________ Date: ____________________
Researcher Signature