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Architects & Fire Safety Engineers; Common Grounds

A Holistic Approach to Integrate Fire Safety Requirements within Building Design

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WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES

Master Thesis in Fire Safety Engineering

Haugesund

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Architects & Fire Safety Engineers; Common Grounds

A Holistic Approach to Integrate Fire Safety Requirements within Building Design

Master thesis in Fire Safety Engineering

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This thesis is a part of the master's program in Fire Safety Engineering at Western Norway University of Applied Sciences. The author(s) is responsible for the methods used, the results that are presented, the conclusion and the assessments done in the thesis.	

Preface

The basis for this research originally stemmed from my desire for finding a way to connect my two passions; architecture and fire safety. And what better way to do so rather than figuring out their commonalities and differences?

As the world is steadily moving into the age of sustainability and environmental protection, working "smarter" rather than "harder" is coming into play. There will be an increasing need for professionals with a broader vision and multidisciplinary knowledge. This will be consequently saving unnecessary time, money, and efforts- thus being more sustainable.

Choosing a somewhat different field for my masters has been quite a challenge, proving to be as intriguing and exciting as I have anticipated. I believe my ability to combine architecture and fire safety will be a major advantage, as I would be introducing a mixture of both specializations and perspectives to my workplace.

Thus, this study will aim at trying to bridge the gap between the two professions, eventually leading to a safer, more sustainable, and consequently more cost-effective projects.

N.B: an article[1] summarizing the findings of this study has been published on Brenn Aktuelt, an online journal by Brannfaglig Fellesorganisasjon (The Norwegian Fire Professionals Joint Organization).

For the full article, please refer to Appendix A.

[1] https://brennaktuelt.no/arkitekter-brannforebygging-branningeniorer/architects-fire-safety-engineers-common-grounds/103774

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In truth, I could not have achieved anything in my life without a strong support system.

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My uncle Maher, my backbone and solid wall, I'll make you proud.

My sister and her family who have put up with my recurring tantrums, and provided continuous ice cream...

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This thesis was created in collaboration with Sweco Norge AS, in which my colleagues at Stavanger office have provided me with a working space, various contacts within the architectural and fire safety fields, and an unlimited supply of coffee and laughter!

Abstract

This thesis aims at researching methods of bridging the gap between the disciplines of architecture and fire safety engineering in the workplace, eventually reaching common grounds. Architects and fire safety engineers almost always find themselves on opposing sides, affecting both of their works' efficiency and resulting in redundant time spent on amending designs.

Generally, a knowledge gap paves the way into trusting those who possess that knowledge without questioning it, just like we trust doctors to know better, as our medical knowledge is limited. Thus, a comprehensive knowledge of both disciplines could prove to be highly effective on reducing controversy and allowing for a knowledgeable debate. Understanding the current system and how it operates is also essential.

Thus, the objective is to understand how each professional views the other; architects/ designers on one hand and fire safety engineers on the other. In some cases, the relationship is quite faulty, as each perceives the other as trying to sabotage their work. Moreover, their knowledge levels will be considered based on their education on one hand and their professional experience on the other. Case studies will further help us understand what went wrong, and consequently how it can be fixed.

Ideally, the findings should be incorporated in both architectural and fire safety educational systems, eventually saving them both time and money by allowing them to get together and draft "achievable designs" from the initiation of the concept design. This thesis advocates for the presence of a fire engineer throughout all phases of the design and construction of a building, from the very conceptual phase into the post construction control and supervision.

Keywords:

Architecture, Design, Fire Safety, Holistic Design

Summary

Humans, in general, have an underestimated perception of risk. Fire, specifically, is considered as a low probability/high consequences kind of event. Thus, rendering it as something not likely to be considered by non-professionals in the fire safety field. For a normal person, being given the choice between living in a beautiful space versus one that's safe in case of a fire (which is something that might never happen) is a no-brainer. Consequently, it's our job as fire engineers to come up with a compromise between safety and aesthetics. This study explores ways to do, as well as the background behind that dilemma.

First, the current system is studied, learning its positives and negatives. We can't fix something if the error is not located in the first place. Then, the project chain of architects who handle certain issues related to fire safety, whether completely or partially, is focused on. That is accompanied by the viewpoints of fire engineers as well, whether those in consultancy positions or research-oriented duties. Then, by learning what they're both educated on at the university level, we can compare that to how they actually apply that knowledge in projects. Are architects capable of verifying that fire safety requirements are embedded in their designs or do they lack that skill? Are fire engineers educated enough to appreciate and try to accommodate the aesthetical and functional requirements of architects?

Furthermore, the above is connected to several case studies to try and link the education received, whether formally or by experience, to the errors that took place in those incidents. Would an improved system of education be able to provide better knowledge and thus lead to improved verification system which in turn can prevent such incidents from happening? Would a holistic and comprehensive system of control and supervision save the day by locating all errors before they turn into disasters?

The study concludes with the necessity of a holistic approach to architectural design. That approach will allow architects to realize the importance of involving fire safety engineers in all design phases, especially in the early design stage. Both, architects and fire safety engineers, will benefit from increased dialogue between the two professions – ultimately affecting the building design itself. Learning about each other's' roles in design will lead to designing functional, aesthetically pleasing, cost-effective, and ultimately safer buildings.

Sammendrag

De fleste menneskene har en tendens til å undervurdere risikofaktorer. Brann er noe som de fleste anser som noe med lav sannsynlighet men høy konsekvens. Dette medfører at mennesker uten brannsikkerhet kompetanse unnlater å vurdere brannfarene. Et hvilket som helst menneske som får valget mellom å bo i et fint hus og å bo i et brannsikkert hus (noe som kanskje ikke finnes) vil velge utseende uten å vurdere det andre. Det er derfor vår jobb som brannsikkerhet ingeniører å finne løsninger som kombinerer sikkerhet og estetikk. I denne studien vil jeg undersøke hvordan vi kan gjøre dette samt bakgrunnen for dette dilemma.

Vi begynner med å undersøke det nåværende systemet for å lære om hva som fungerer og hvilke svakheter som finnes. Det er ikke mulig å fikse opp i noe hvis vi ikke kjenner til svakhetene i den. Studien vil etter det fokusere på de forskjellig arkitekturer som håndterer brannsikkerhet prosedyrer, enten helt eller delvis. Samtidig skal vi belyse brannsikkerhet ingeniørers sine meninger, både dem med en konsulent jobb og dem som har forskningsoppgaver. Når vi finner ut hvilke kompetanser begge tilegner seg gjennom studiene kan vi sammenligne hvordan de bruker kunnskapene i praksis. Har arkitekter forståelse av at brannsikkerhet skal være integrert i deres designer eller mangler de denne kompetansen? Er brannsikkerhet ingeniører opplært nok til å sette pris på og implementere den estetisk og funksjonell prinsipper til en arkitekt?

Videre vil dette bli knyttet til flere casestudier for å se sammenhengen mellom kompetansen, både den kunnskapsbasert og den erfaringsbasert, og de feilene som har hendt i disse tilfellene. Kan et bedre utdanningssystem gi bredere kunnskap og dermed et bedre tilsynssystem som vil fange opp slike tilfeller før de eventuelt hende? Ville et helhetlig og omfattende tilsynssystem kunne lokalisere alle feil før de eventuelt blir til katastrofer?

Studien konkluderer med nødvendigheten av en helhetlig tilnærming til arkitektonisk design. Denne tilnærmingen vil tillate arkitekter å innse viktigheten av å involvere brannsikkerhetsingeniører i alle designfaser, spesielt i den tidlige prosjekteringsfasen. Både arkitekter og brannsikkerhetsingeniører, vil ha en stor fordel av en økt dialog mellom de to yrkene - noe som vil påvirke selveste bygningsutformingen. Å lære om hverandres roller i design vil føre til å utforme funksjonelle, estetisk tiltalende, kostnadseffektive og dermed tryggere bygninger.

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Abbreviations

FPE = Fire Protection Engineer
FSE= Fire Safety Engineer
REN = *Rasjonell Elektrisk Nettvirksomhet* - Rational Electrical Network Operations
TEK = *Teknisk Forskrift* – Technical Regulations/ the formal legislation that must be satisfied.
VTEK = *Veiledningen til Teknisk Forskrift* – Guidelines/ Suggestions to the Technical Regulations

Methodology

The research methodology follows a qualitative exploratory approach, focused on gaining insight and understanding the underlying reasons. This has entailed surveying several architects and fire safety engineers, to consequently figure out what issues they face when dealing with each other. Landscape architects as well as fire lab researchers have also provided their views on the matter. Then, the discoveries were summarized into the elements considered as the major current issues, and compared against the research questions, and subsequently solution were presented as to how to overcome the differences and reach an agreement between both disciplines on those issues.

Data Collection

Usually, for a qualitative research, the most common data collection methods are interviews, focus group discussions, observational methods, and document analysis. For this report, we will be combining interviews and document analysis, thus enhancing the credibility of the study using data triangulation.

The interviews were used to explore the opinions and views of each of architects, fire engineers, landscape architects, and fire scientists/researchers. Some of the architects and engineers approached have a vast pedagogical experience along with their professional one. The interviews' mediums included emails, face to face interactions, as well as phone and video conversations. Moreover, several webinars reflecting on the matter were attended and analyzed.

As for the document analysis, it consisted of reviewing various literature related to architecture, fire safety, and the connection between the two fields. Several articles explaining different fires and their causes also helped in understanding what went wrong, which would lead the way into developing methods for how to prevent such incidents in the future.

1. Introduction

This research was motivated by the bridging courses I was required to attend at Western Norway University of Applied Sciences before starting my master's courses in Fire Safety. Coming from a very different background in architectural engineering, fire safety was quite a foreign concept to me. We had studied about the importance of installing fire rated doors and such, but not the background and reasoning behind that.

As architects, we tend to think aesthetically, yet always having functionality and usability in mind. This usually leads to issues with "engineering" minded people, such as civil and mechanical engineers. Studying fire safety made me realize the criticality of architectural design to fire safety just as much as other engineering disciplines. That left me questioning the connection between building design and fire safety, and thus; the relationship between architects and fire safety engineers.

Since I'm in the process of becoming a professional looking to combine architecture and fire safety in the workplace, I needed to understand the challenges facing both disciplines when dealing with each other. To what extent do they understand each other's requirements and design according to the impact they have on one another? How would it be possible to involve fire engineers in the architectural design phase, starting from the preliminary design all the way to the actual construction? And how beneficial would that be?

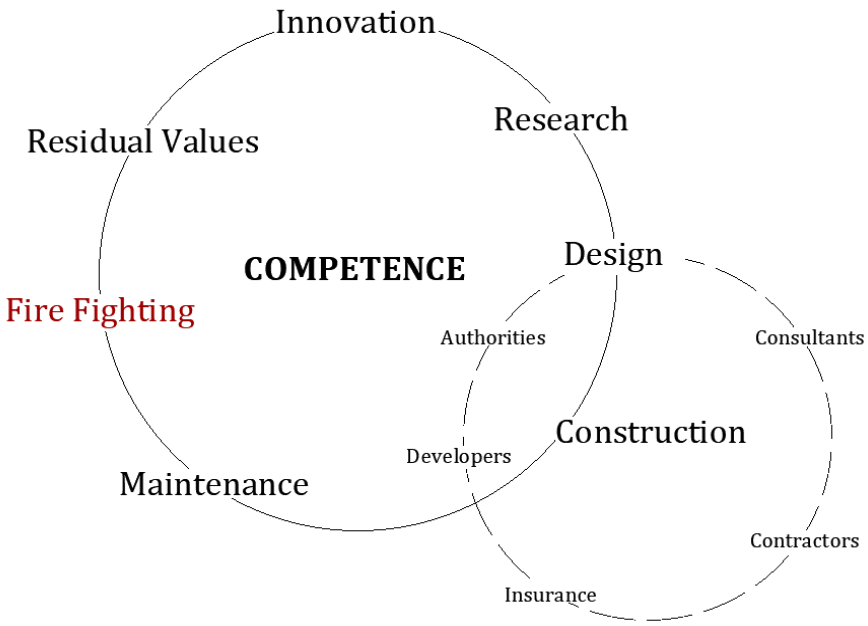

Figure 1 Showing the Various elements that go into a certain project

The above figure was adapted from a presentation in an SFPE webinar titled "Performance-Based Design of Fire Safety in High-Rise Timber Buildings" by Robert Jonsson from Sweco and Carl Pettersson from RED Engineers. Its purpose is to show that what we see above is only the tip of the iceberg, and what actually goes into the full process is much more complicated and involves a large number of players who sometimes need to be working individually and at other times have to cooperate with each other, and thus need to fully understand each other.

1.1. Background[1]

The below illustrates a cooperation trial between designers and fire engineers in the workplace. The results were what motivated this study, as to understand whether such a cooperation would actually be beneficial in reality and not just theoretically.

In 2011, a collaboration initiative between the BRE Centre for Fire Safety Engineering[2] and Foster + Partners resulted in a member of the former joining the team of Foster + Partners in Edinburgh, UK for 8 months. His role was to aid the designers in creating inherently safer buildings in terms of fire safety.

The original thought was that the fire safety engineer would solve arising fire issues for the design team. "The 'In-House Fire Safety Engineer' would become known as the 'Fire Safety Advisor' or more simply, the 'Fire Guy'." (Woodrow, 2017)

However, outsourcing fire problems to the "fire guy", whether in house or not, resulted in a lack of integration that would lead to eventual compromises on the original design for the fire strategy to work. Thus, the "fire guy" needed to have three roles, in which engineering – or solving problems- was the third and last. Those roles should be as follows:

1. Identifying problems using fundamental assumptions that remain valid regardless of the context they're in. Thus, explaining problems and the reason behind them to designers improved their understanding of the criteria they need to aim to achieve, and thus increased choices they have.

Formerly, designers at Foster + Partners were used to define problems according to code compliance, since they didn't possess the adequate fire safety knowledge. However, since more irregular designs were being introduced, prescriptive codes were becoming more redundant. Therefore, problems defined based code compliance were not necessarily fire safety problems.

2. Once designers have gained a clear understanding of fire safety objectives, they can start achieving those objectives themselves. Architects need to consider different integrated variables and design objectives associated with the building to achieve an optimised design. Thus, once they know and understand what they need to achieve with regards to fire safety, they start producing innovative solutions to such problems, optimised for their unique building.

Previously, architects didn't have confidence in their own ability to create fire safe solutions. Discussions with fire experts and critique of the architects' solutions led to increased understanding in the background of things and issues involved, thus increasing the quality of solutions put forward by architects.

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[1] Adapted from an Article by Michael Woodrow: "*Fire Safety Design, Through an Architect's Eyes*." (Woodrow, 2017)

[2] The BRE (Building Research Establishment) Centre for Fire Safety Engineering is the research group at The Institute of Infrastructure and Environment, University of Edinburgh conducting research in fire, structures and environment.

3. The third and final role for the fire safety advisor was to justify the selection of fire safety solutions by proving their effectiveness, which was something that rarely happened. Creating a fully optimised building design was much more difficult than just reviewing drawings. On one hand, a fire safety engineer is presented with lots of possible choices and solutions while working with solely the fire safety variable. On the other hand, however, the architect must optimise the building design while juggling and compromising variables. The experience resulted in that the in-house fire safety advisor was only asked to step in to produce viable solutions of his own once during the 8-month period. The designers took care of all the other cases.

The experience demonstrated the potential, and perhaps the need, for a new role in fire safety. A job which requires a comprehensive overall perspective and capability to relay specific technical information to design teams. Unfortunately, there are only a handful of individuals who have the necessary knowledge to fulfil a double role.

Thus, the addition of a fire safety advisor to an existing design team would lay the bedrock for the consideration of various variables from the initiation of the design process, including fire safety. This, in turn, would allow designers to fundamentally, positively alter the design to produce better designs.

1.2. Scope and Limitations

The main scope of this research will be the architect and fire safety engineer relationship, though lots of commonalities will be found with other types of engineers (mechanical, electrical, civil, etc.). The scope of the Fire Safety Engineer will also be limited to those who handle onshore construction projects, and not offshore projects or industrial based responsibilities. Consultant fire engineers as well as research focused ones will be studied. Architects will include designers of architectural projects and will not include interior architects. Landscape architects will also be included in the study.

1.3. Definitions

Architect/ Designer:

Architects, as a title, may include those practicing various specialties, from large scaled urban city planning up to the smallest scaled furniture design. However, the below research will be addressing “architects” as those confined to designing and constructing buildings, internally and externally. Nevertheless, a small part will also be dedicated to understanding landscape architects’ views on how fire safety requirements affect their work, and their role in ensuring the production of fire safe buildings and their surroundings.

Fire Safety Engineer FSE/ Fire Protection Engineer FPE/ Fire Safety Professional:

According to SFPE and the Institution of Fire Engineers, this will encompass anyone having professional qualifications to handle fire engineering studies, which includes the application of scientific and engineering principles, standards and regulations, and expert judgement, based on a comprehensive understanding of the phenomena and effects of fire, as well as of the reaction and behavior of people in situations that involve fire. Their goal is to protect people, property and the environment from the destructive effects of fire. (The Institution of Fire Engineers, 2014)

2. Problem Definition

The below will define the problem at hand and try to locate the background of this problem, in order to fully understand and eventually come up with solutions.

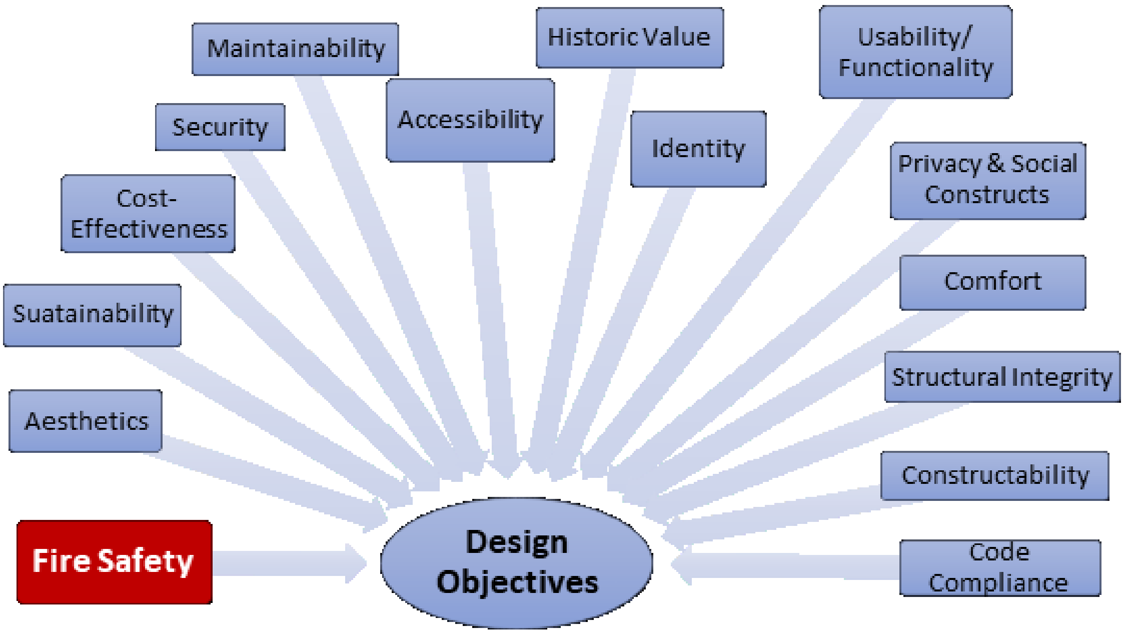

Figure 2 Various Design Objectives of Architects - adapted and modified (Park, 2014)

Designers (including architects) are trained to consider various design objectives related to both form and function of a building. Figure 2 above shows the various objectives often addressed by architects, among others. However, one of the least considered variables, which could fundamentally affect and alter the building design, most often negatively, is “Fire Safety”. (Woodrow, 2017)

Fire engineers are held responsible for abiding by the codes and regulations when developing their fire concepts. Thus, they have the main authority and accountability when it comes to ensuring that the buildings in question are deemed as safe in case of a fire. However, they build their fire concepts upon a pre-existing and often complete designs, created by architects.

And even though architects tend to review main fire codes and work with fire safety engineers, the collaboration between the two disciplines is so minimal that it leads to a mis-informed and unoptimized approach to fire safety. A system that could use up some improvement.

The question is: How?

The intention is exposing architects to the concept of a holistic approach to safety requirements, including fire safety, thus allowing them to realize the importance of involving fire safety engineers in all design phases, especially in the early design stage. Both, architects and fire safety engineers, will benefit from increased dialogue between the two professions – ultimately affecting the building design itself. Learning about each other's' roles in design will lead to designing functional, aesthetically pleasing, cost-effective, and ultimately safer buildings.

2.1. Intrinsic Differences

Are architects and engineers intrinsically different in a way which prevents effective collaboration? As an architect, we have been told during our studies by those with more experience, that we will always be on opposite sides of engineers, as we have completely different ways of thinking, and different sets of priorities. But is that scientifically true or just stemming from a lack of desire to try to understand each other?

Several research documents have highlighted certain intrinsic differences between architects and fire safety engineers, those that could lead to an ineffective collaboration. These differences include but are not limited to different communication styles, language issues, and different perspective and priorities. Regarding communication styles, architects are usually right brained, which drives them into thinking in an artistic and aesthetic sense, while engineers are mostly left-brained, thus more analytical and scientific in their approaches. As for language issues, that is usually revealed when architects and engineers might use the same words but have different conveyed meanings to those. The last intrinsic difference might be the most important one in relation to our study. The fact that architects and engineers have different perspectives and priorities might create high levels of controversy. An architect or designer will mostly be focused on access, pedestrian flows, visual environments, etc; while the fire engineer would be occupied with the means of egress, fire separation, occupant numbers, etc. These terms might refer to the same issues, but will definitely be handled differently, as the usage priorities are vastly different.

2.2. Research Questions

The below research questions will summarize what the following pages will try to address, and eventually find an answer to.

- **Is what architects learn sufficient for them to effectively design fire safe buildings, or to at least collaborate efficiently with fire engineers?**
- **Will a more holistic approach to building design yield successful results? How can that be done?**
- **Would the engagement of a fire engineer from the very beginning of the conceptual design be feasible? Or would that simply add unnecessary financial burdens and unwarranted billable hours?**

3. Literature Review

The below literature review is aimed at understanding how various literature sources have addressed the issue of architects and fire engineers' collaboration, mainly in terms of a holistic approach to both architectural design and fire safety. It also addresses what architects would need to know in order to achieve an effective fire safety performance.

"Fire safety is an important need, although it sometimes has a lower priority than other design objectives due to its intrinsic nature and the low level of risk perceived from fire: fire safety features do not generate any explicit benefits such as comfort, convenience, or aesthetic pleasure, and they are only useful for a fire incident, which is not likely to occur. Considering the common and widely accepted perception that architects place more importance on artistic and aesthetic expression in building design (i.e., form over function), a lack of focus on fire safety may not be an exaggerated concern (Fischer & Guy, 2009). A proper level of fire safety, however, as a public good, should be provided to all buildings regardless of the design priority of architects. Therefore, fire protection measures have been enforced in the form of regulations, commonly via building codes and standards, in which various requirements are listed. As such, although the design concept may originate from visual sense or aesthetics of buildings – attributes which are not subject to the building codes– the architects' design decisions may need to be changed to satisfy the codes. This may be one of the reasons that some architects perceive code requirements as design constraints". (Park, 2014)

Because fire engineers are the ones responsible for developing fire safety designs based on existing codes and regulations, they are often viewed as the key authority in charge of ensuring the fire safety of buildings. However, their task originates with specific building design features, such as interior spatial layout, exterior shape, site plan, and so on, which are typically determined by architects. (Park, 2014)

And even though architects design buildings within the restrictions of regulatory requirements, their focus is rarely steered towards fire safety, but rather to the visual and aesthetical configurations. This can consequently result in controversies with fire safety objectives in such a way that buildings can be deemed unsafe in certain situations due to unintended effects of building design features on actual fire safety performance. (Park, 2014)

Based on newly introduced regulations, architects have become more open to the idea of integrating health and safety into architectural design. Similarly, fire safety can also be embedded. For that, working with specialists in the fire industry, such as fire brigades, fire safety engineers, and professionals, can aid in developing suitable fire safety measures which would be applied by architects and abide by relevant building regulations for various building types. (RIBA, 2015)

3.1. Knowledge Set for Building Fire Safety Performance

In order to come up with effective building design decisions, one must properly define the attributes influencing a building's fire safety performance, as some might be related to building design and others won't. One of the best data sources for those are fire incident reports, which usually include building descriptions. Analysis of those reports resulted in extracting building design decisions for the three design phases during which most building details are determined. (Meacham & Rodriguez, 2014)

- **Phase 1: Predesign**
    - *Building Regulations*

Buildings are supposed to be designed while abiding by regulations, and thus those regulations should be checked before starting with the design process. In addition, designers might not know that performance-based comprehensive approaches to fire safety are always an option. However, sometimes the usage of those solutions is restricted by building officials who prefer prescriptive solutions.

Thus, it is essential that all those responsible (building officials, designers, and fire safety professionals) are on the same page when it comes to the approach to be used, before initiating the actual building design.

- *Occupancy / overall building floor area/ height*

Occupancy (building use) is very critical for fire safety as it determines the characteristics of users and possible fires. Thus, once occupancy is decided upon, fire safety engineers should be included and informing the architects about the required characteristics of that specific occupancy.

- *Environmental conditions (temperature, wind, humidity, flood, hurricane, vegetation, soil, hydrology, seismic zones)*

Environmental conditions can highly affect fire safety performance. For example, wind direction influences the movement of smoke and flame spread within a building, besides either helping or opposing firefighters' in their rescue mission. Thus, it needs to be considered, especially in areas where consistent and strong wind is expected.

- *Communal environment (rural, urban, tourism, large city, existing structure)*

High proximity and preparedness of fire brigades is beneficial to fire safety. However, that's not always possible due to limitations in man power and appliances. This might require internal fire protection systems and studies investigating fire propagation especially in dense areas. This also poses the importance of façade materials, buffer zones and separation distances, location and sizes of openings... etc.

- *Infrastructures (traffic, gas, electricity, water)*

In cases where water resources are limited, separate sources should be provided for internal and external firefighting measures. Power sources need to be constantly provided for active fire protection measures. Moreover, electricity, if poorly maintained, can act as a major ignition source. Traffic, on the other hand, can highly affected response times for fire brigades and ambulances. Thus, stricter internal fire measures should be placed in areas with high traffic.

- *Site history and historical value*

Restrictions on historical sites can affect surrounding roads and emergency response times and accessibility. Furthermore, limitations on choice of materials can apply based on required harmony with existing surrounding historical buildings, which in turn may not have enough fire safety characteristics as their modern substitutes.

- **Phase 2: Schematic design**
    - *Project objectives and design concept*

Design solutions to achieve intended project objectives are decided upon in the schematic design phase. For instance, if the building is supposed to achieve a green design, approaches such as using eco-friendly materials, solar systems, double façades, and such are determined in this phase. In that case, fire hazards stemming from these approaches must be investigated early on.

- *Building orientation and schematic site design*

The site design (including the building's orientation) is affected by required views (to and from the building), daylight conditions, site typology, access routes, among others. However, when it comes to fire conditions, the relative direction of the building entrance to other existing buildings, parking lots, and fire fighters' access routes are vital features for fire safety performance as they can determine the occupants' egress direction and the effectiveness of rescue activities. Mustering areas outside the building should also be sized according to expected number of occupants.

- *Occupant flow or circulation (parking, elevators, escalators, stairs)*

Occupant flow and circulation paths used in normal working conditions are essential, as occupants will tend to use the same pathways in emergency conditions. Secondary egress routes should be accessed easily from the elevator area, and architectural features play an important role in that.

- *Spatial design and schematic space allocation*

In spaces where large or fast developing fires are expected, smaller scaled spaces are desirable, as fuel quantities are linked to space size, higher heat release rates are obtained in larger spaces over shorter periods, specifically those with low ceilings. Danger of ignition is also affected by space use. Location of rooms is very important as well, as flames tend to spread easier horizontally than vertically, lower floors are somehow safer when high risk areas are placed on higher floors. Furthermore, rooms which are expected to host large numbers of people simultaneously should be placed on ground levels with direct egress paths to the outdoors.

- **Stage 3: Design development**
    - *Site plan and landscaping*

Within this phase, further details for the site plan and landscaping are determined, including hydrant locations, firefighter's access routes, police control lines, and possible blockages of those. It should also be considered that building ornaments, sculptures, and vegetation would not add up to existing fuel amounts, ignition possibilities, or hinder evacuation or emergency response.

- *Floor plans and sections*

Exit locations are to be determined according to occupants' use and their respective characteristics. At least two distant exists should be put available, in case one of them is blocked or fails. In case only one of the exits is expected to be used in emergencies, that indicates issues with the floor plan itself. Fire protection systems in place could also affect the number of exits needed. Moreover, spaces expected to host large numbers of people or specific type of activities might need different measures. Occupancies with low familiarity levels (hotels, airports, etc.) should have extremely clear signage and spatial configurations for easy wayfinding.

- *Structural system and roof system*

Structural integrity is major role player in safekeeping firefighters' lives, as structural failure will usually take place during their mission. Innovative structural systems should also consider the structural performance in fire conditions, besides normal operations, and their effect on firefighters. An example would be in the employment of green roofs (with vegetation) or solar powered panels, and such technologies.

- *Building envelope design*

One of the major issues in fire safety is fire spread throughout the building envelope, posing threats of flames reaching nearby floors through openings. For that, adjacent openings should be provided with enough vertical separation distance or long enough spandrels such that vertical flame spread is less likely along the building envelope. The geometry of the façade also plays a role in flame spread, as outwardly slanted surfaces contribute to flame movement. Equipment placed on rooftops (advertisement panels, HVAC units, etc.) can add to the dangers of short circuiting and might cause a difficult to detect fire or contribute to an already existing one. Fire can also spread downwards through burning falling objects.

- *Interior finishes*

As interior finishes are not there solely for their combustibility characteristics, aesthetics play a major role in their choice. Colors, textures, acoustic performance, all are parts of how occupants perceive the relevant space and recognize locations within a building, as well as aiding in orientation to exit routes. (Park, Meacham, Dembsey, & Goulthorpe, 2014)

3.2. Why Buildings are Better When Architects and Engineers Collaborate

As we have seen that lots of elements in architectural design can have major impact on fire safety, would it be correct to say that collaboration between architects and fire engineers can create better buildings?

Working together, architects and engineers can come up with design solutions that are better than their individual ones. Exchanging knowledge and information, especially at the early stages of a project, eventually leads to better buildings. The technical input that an engineer can provide is much more useful when improving building energy efficiency is considered.

Founding director of Webb Yates Engineers- an engineering firm that works closely with architects- Steve Webb, says that firms that are often more open to different points of view achieve better results. He states that it is particularly satisfying to work on projects in which all parties have a mutual understanding of how different disciplines work: it helps to put the design relationship on a more equal footing. He is a sustainability-focused engineer who believes that the best project outcomes are derived from early co-operation between engineers and architects

Within the offices of Webb Yates, which also includes architects, a mixture of architecture and engineering projects are created. Those projects are usually led by the architect within their sub office “Interrobang”. It is a London-based transdisciplinary architecture and engineering practice. Founded in 2015 within Webb Yates Engineers. It provides coordinated architecture, structural, civil, and building services engineering.

Webb advocates that engineers, whether structural, mechanical, electrical, or others, should be brought involved in the projects at an early stage. While there is a cost incurred, it is likely to save money in the long run. “You do not have to pay very much to get a structural engineer or an M&E engineer to sit-in in meetings at Stage 1, when their input can have a positive influence on design decisions at a far more cost-effective point," he points out.

If engineers are involved early enough, Webb reckons that they can not only help create a more interesting physical structure, but a project that stands up economically and sustainably as well. As the building environment is more likely to have an increased focus on sustainable materials as timber and stone and reducing embodied energy, engineers’ roles will also consequently increase.

“Architects and engineers understandably do not like to consider ourselves to be part of the problem, but as long as designs stick with materials such as concrete, steel and bricks, they are contributing,” he states. (Webb, 2019)

3.3. Proactive Collaboration with Architects

Architects might have a limited knowledge in the availability of options for fire safety design, be it prescriptive, performance based, or a mixture, besides continuous developments in fire science and simulation technologies. Furthermore, they might not be fully aware of how their different design features can affect the fire safety performance of a building.

Thus, Fire Protection Engineers should help architects understand their role in fire safety, while recognizing them as key players in that, as they could – relatively easily- embed fire safety design into their architectural approach. Architects could highly benefit from an integration of fire safety principles into their education and trainings. For instance, well distributed exits throughout a floor plan, according to location of occupancies, number of users, and occupant flow, can decrease the required egress times.

Moreover, using specific colors, textures, lighting concepts, or iconic objects, can significantly increase the users' cognitive perception of the space. This, in turn, helps avoid disorientation in less familiar buildings such as hotels, airports, or shopping malls. Additionally, using vertical circulation paths that are already part of everyday use as exit pathways can be very helpful in emergency situations, as it decreases irrelevance and improves movement. (Meacham & Rodriguez, 2014)

4. The Current System – How does it work?

With every system that governs a certain relationship (the building construction system in this case), there is always points that indicate both the success and failures of that certain system. The following chapter will highlight what's good and what could be improved about how the construction industry handles the designer/engineer relationship. First, an international point of view will be presented, followed by what takes in place in Norway, and finally the system in Lebanon. Comparing the three variables will aid in deciding what's good and what's bad with each system, and thus reaching a conclusion on how to improve them for a better holistic approach to fire safety.

4.1. International

Globally, systems that govern the methods in which a building is constructed - starting from the initial project scope through the detailed design, permits, construction, and eventually operation and usage – can vary greatly from a country to another. Some countries have a bigger influence of official authorities during various phases, while others rely mostly on private enterprises with minimal intrusion of governmental parties.

The coming pages will be discussing how Norway and Lebanon run the process of constructing projects. Scandinavian countries have quite similar systems to the one currently applied in Norway though differences will inevitably be found. Nevertheless, if we are to consider Arab countries, and especially those belonging to the GCC (Gulf Cooperation Council), we'd notice that the government is responsible for following up with almost all the details, as permits are provided during all various phases, and supervision and control levels are quite high. Moreover, in those countries, the presence of a fire engineer is essential but from a standard applicator point of view, as deviations from those standards are rarely accepted. Thus, these countries follow more of a prescriptive rather than a performance-based approach. This is not the case in Scandinavian and European countries.

4.2. Norway

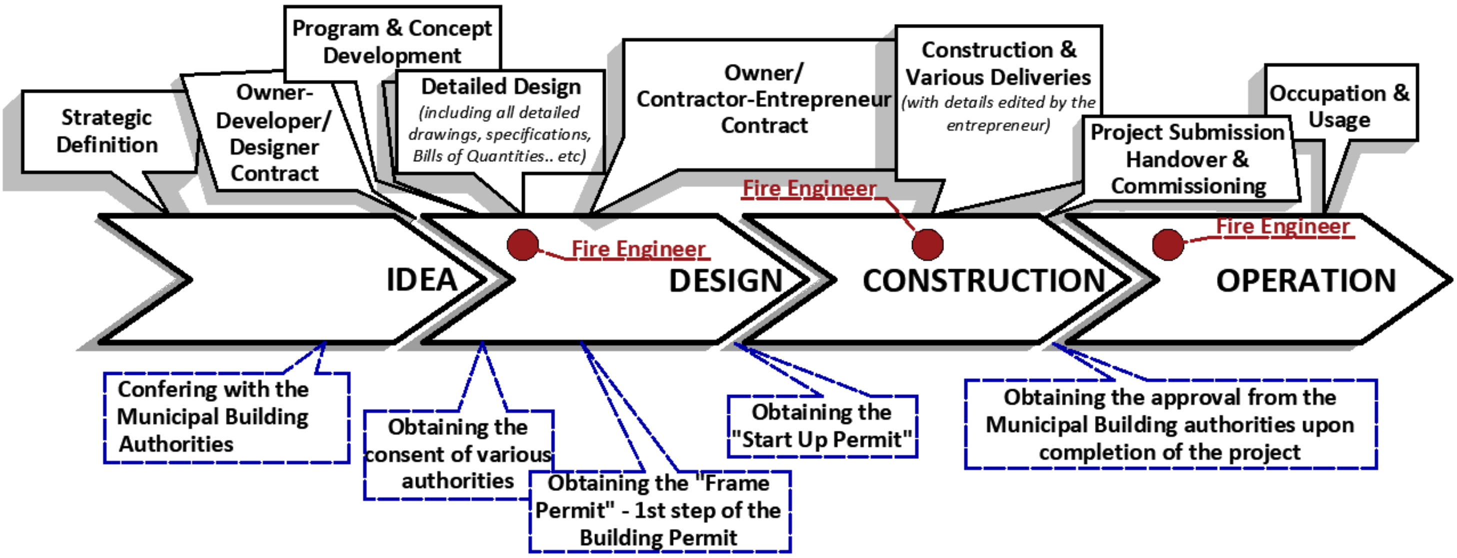

Figure 3 Norway- From Project Scope to Occupation & Usage

Figure 3, partly adapted from (Hjelseth, 2015) and (NTNU, 2019), shows the process of constructing a building in Norway and eventually putting it into use. The series of steps are depicted in Figure 3 and further elaborated below. The “Building permit” application process is also presented, as this process has both a direct and an indirect impact on a large number of elements and is therefore a good introduction for understanding all the components and relations.

It is worth mentioning that the Norwegian Building Authority is the main party responsible for the implementation of technical regulations, as well as being the inspection authority that ensures total compliance with the rules regarding product documentation and administration of the central approval of enterprises according to the rules set in the *Planning and Building Act.*

Generally, the aim is that all buildings need to be sustainable and accordingly beneficial for both individuals and the society as a whole. Thus, there are some issues that receive extra attention, such as health, the environment, safety and security, as well as overall sustainability requirements. This is applicable for both new and existing buildings, which in certain cases need to be retrofitted or rebuilt with these systems. In order to achieve these goals, the Building Authority cooperates with other parties from each of the construction industry, consumers and other organizations. The Building Authority also works closely with other Nordic authorities and bodies related to the European Economic Area (EEA). (Hjelseth, 2015)

As for the detailed description of the building process, it goes as follows. First, a start-up meeting takes place to initiate the project plan. Municipality representatives take part in that meeting to make sure that the project contributes to the realization of the municipality’s overall plans. Afterwards, the work needs to be planned and organized, which in turn will be translated into an actual project plan. Regular meetings with municipality representatives will be arranged. Moreover, at this phase, logging systems for all various actions and notifications will be put in place. This can be summarized into the project scope phase. A strategic definition is underway at this point.

Before the actual design is instigated, the owner will have drafted and signed a detailed contract with the designer/architectural firm which covers all aspects of the required services from each party. The architect then develops a fully detailed design scope and maintains the connection with the authorities to obtain various consents. The contractor/entrepreneur takes over in this stage and starts implementing the vision of both the owner and the architectural designers.

We will be discussing in the following pages how the system works in Lebanon, in which the two main differences between the systems in Norway and Lebanon are the involvement of the fire engineer in the process and the required number of construction and building permits.

In Norway, the fire engineer has a much bigger role, as in Lebanon he/she could sometimes be non-existent. The fire engineer is usually introduced in Norway at the design stage (even though that varies from a project to another), but at different times within that stage. Ideally, that happens within the early design stages, though most of the times that is not the case, as sometimes the fire engineer is required to proof and amend finished architectural designs. However, the fire engineer is mostly involved in the construction stage, and in the operation stage, especially in special fire objects where periodic investigations take place to make sure that the building still complies with the required fire standards.

Moreover, the contractor/entrepreneur has a much higher degree of flexibility in making amendments in the design. They can easily substitute solutions (including those related to fire safety) with others that they deem acceptable. Usually that is done following a set of broad requirements and set criteria (which can at times be faulty) that need to be abided by. This step can lead to major issues (as will be seen in Chapter 8, Control & Supervision)

4.3. Lebanon

The process of constructing a building in Lebanon and eventually putting it into use is conducted through a series of procedures and steps, as is mentioned in Figure 4 and will be further elaborated below.

It is worth noting here that in the case of public buildings, it is obligatory to go through a public bid to choose the main and sub-contractors. But we will not discuss that in this paper, as it includes specific rules and regulations set by the government for each building.

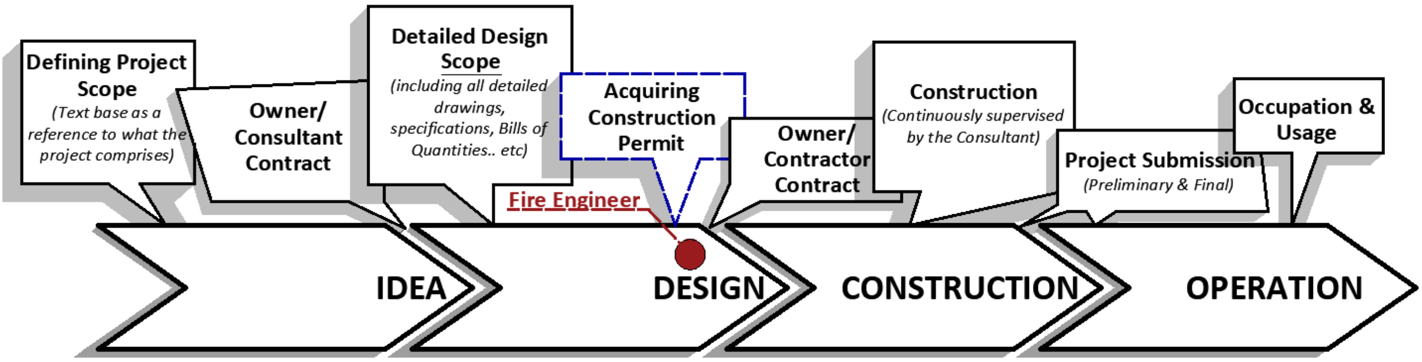

Figure 4: Lebanon - From Project Scope to Occupation & Usage

As a first step, and similar to the Norwegian systems, the project scope has to be defined. This is usually done by the owner and their consultants. A project scope is that which includes the main requirements of a project (building type, size, lot location, capacity, general approximate budget, project stakeholders, specific requirements, etc.) The scope should be able to provide a clear understanding of the needs of the project, at its preliminary stages. The project scope is what allows the owner to draft a contract with their consultant.

What follows that is a detailed design scope, specifying every aspect of the requirements of the project, along with a stricter budget. Unlike the project scope which typically consists of text, the detailed project scope usually includes architectural drawings of the project along with minor civil and mechanical drawings. This step allows for the recruitment of contractors for the project. The contract specifies owner-contractor relationship in terms of Scope of Work, Payment Terms, Responsibilities of both parties, Project Change Notice, Insurance & Risk Management, Force Majeure, Schedule Guarantees, Subcontracts, Applicable Law, and Arbitration procedures.

Simultaneously, the consultant would be working on achieving the required approvals. Contrary to other countries which require permits and approvals for governmental parties and civil defense authorities, the only authority in Lebanon responsible for issuing those approvals is the Order of Engineers and Architects. Although it is a non-governmental syndicate, it is responsible for representing engineers of all majors and architects in Lebanon. It governs the whole construction industry through several aspects; mainly through issuing construction permits. That permit provides them with a distinct number and ID used to sign and legalize documents.

Until this point, fire safety is still not considered within the project. The introduction of a fire engineer is shown in Figure 4 as an indication of the earliest point of introduction, which is, in most cases, done in much later stages, if done at all.

On the other hand, the only obligatory building codes are those stated by the order as “Building Laws and Regulations”. These set of rules and regulations are divided into prescriptive codes and performance-based codes, exactly as the ones in the Norwegian system. As those codes were derived from the French ones, they are extremely similar to those applied in the EU. A prescriptive code is that which states how the building is to be constructed, while a performance-based code states how the building is to perform.

Those set of rules range from covering major issues such as building footprints, setbacks, and parking requirements, all the way into very minor details such as wall and slab thicknesses. It also includes some environmental concerns embedded within those codes (such as exempting buildings with double walls and clay tiles from certain taxes[1], which has been lately drastically improving. For example, Table 1 shows the number of studies registered at the syndicate, as some of those studies have become mandatory in 2017. It is worth mentioning that “Technical Reports” includes those conducted for Fire Safety measures, which are still **not a requirement in Lebanon**. Unfortunately, only 351 studies have been done within a total of 14,213 building permits (only 2.5%) acquired within the same year[2].

Study Type	Number
Traffic Impact Study	92
Geotechnical Study (Soil)	1937
Technical Reports Study	351

Table 1 Showing the Number of Supplementary studies registered in 2017

While the construction law only asks for the existence of **fire exits as safety measures**, what could be regarded as a positive aspect is that most consultants are resorting to certain fire safety measures as a personal initiative. This is due to the fact that **insurance companies** are requiring an incorporation of basic fire safety measures as a condition for coverage. However, very basic studies are being conducted and usually they’re just going with the easiest and most available solutions, namely basic fire detection systems and sprinklers. Nevertheless, it is an important step forward, even though it only currently applies to public and commercial buildings and excludes residential ones.

It’s also worth mentioning here that within the Lebanese construction law, it is mandatory to create something called a “construction joint” within any building span which exceeds 30 meters. This joint indicates that the building itself is built in two completely independent structures. In the case of a fire or earthquake, this joint acts as a complete separation in the event of the collapsing of part of the structure.

[1] Based on the Lebanese Law of Construction, modified continuously to include current environmental concerns, in which the part related to double walls was put into action in 2005. (Order of Engineers & Architects in Lebanon). However, both the website and the construction law document are only published in Arabic.

2 Based on the annual report published by the Order of Engineers and Architects in Lebanon for 2017. (Order of Engineers & Architects in Lebanon) – refer to Appendix B

A scientific committee of engineers and architects (which does not include a fire safety engineer) at the order study the project and provide their approval for construction or the requirement of certain aspects so that the project conforms with building laws and regulations. Once the necessary approvals are acquired, the consultant then presents their project to the municipality which the project falls under its jurisdiction, on an **informative basis only**. The construction permit is usually granted at this stage, and it is the only permit required when constructing a project. The construction can then initiate.

The consultants assigned for the project will be responsible for representing the owner/s in supervising all aspects of the project and taking required actions with the contractors to conform with the specifications and deadlines. Once the project has been finished with a minor margin of modifications, the contractor performs a preliminary submission. The final submission, in which the project will be ready to be put in use, will be performed within a deadline. In certain cases, the final submission can take place after the building starts operating, in instances where the modifications required are minor enough not to disrupt operations.

4.4. Conclusion

Thus, as a conclusion, we find that the systems in both Norway and Lebanon are still somehow lacking when it comes to fire safety, with the one in Lebanon being almost completely lacking. For that, we would need to know more about what architects and fire engineers think of the relationship that governs them, as well as ways to improve that relationship, as that could be one of the reasons behind the issues with the current system. This brings us to the next chapter, in which we'll be looking at various viewpoints from architects (both design and landscape), fire engineers, as well as lab scientists. Understanding what they think would be the first step to lay down the common problems hindering that relationship, and eventually how to overcome them.

5. Viewpoints

If we are to understand how the current system functions, speaking to those who go through those issues on a daily basis is of utmost importance. Thus, the following chapter will be discussing what each of architects and fire engineers think and perceive the problem at hand. Do architects believe the problem, if present, lies in their lack of knowledge or understanding? Or do they think that fire engineers are to blame? What about fire engineers, do they perceive designers as their allies or adversaries who just make their lives difficult? The below will be summaries of interviews conducted with professionals from both field, which will consequently help us understand how to proceed with the topic.

5.1. Architects' Views

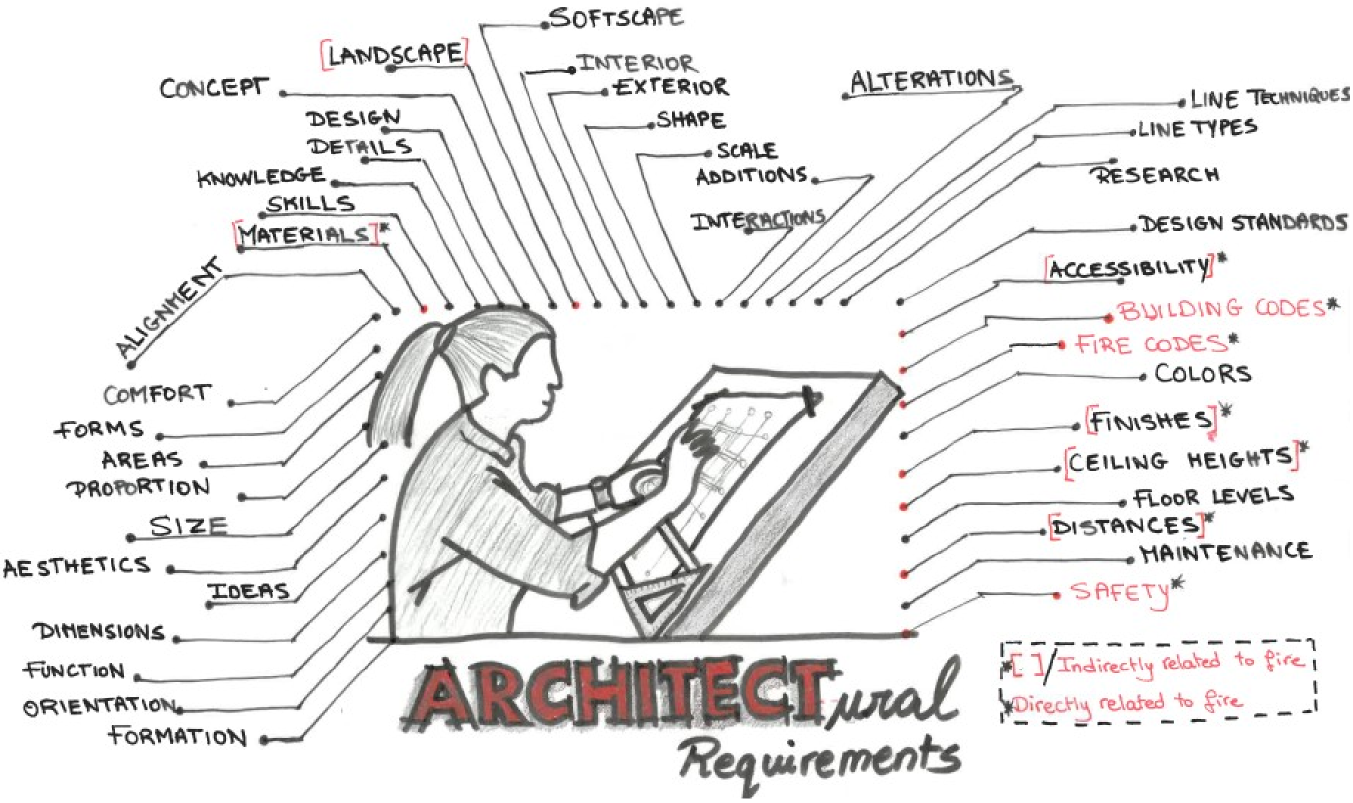

Image 1 Illustration of the requirements of architectural design (self-drawn)

The above illustration (self-drawn) signifies all the various requirements that are going through an architect's mind during the design process. A juxtaposition of different elements should be holistically considered to ensure an effective design, which is quite a difficult achievement, yet not impossible. Regarding fire, there are several considerations (highlighted in red) which are essential and straightforward to achieving a fire safe construction. However, there are also the less considered elements which indirectly affect fire safety (in red and within the box brackets), and which can be unconsciously not linked – at the least in the architect's mind – to fire safety. The below discusses various views of architects and their perception of fire safety and the architect/fire engineer relationship.

5.1.1. Nabil Mohareb

Regarding an international point of view, Professor Nabil Mohareb, Head of the Faculty of Architecture- Design & Built Environment, Beirut Arab University/ Tripoli branch, was contacted. Prof Mohareb has around 20 years of experience in both education and architectural practice. He mentioned the fact that within international projects, especially large scaled ones, technical parts such as fire safety issues are tackled by field experts rather than architects. This results in the architect becoming merely a coordinator between the design vision/concept and the experts, which in turn negates the required holistic role of architects. However, in smaller scaled local projects, and as the budget might be quite limited, architects can resort to the applicable guidelines of the country and completely handle all aspects of the project design, including the fire safety part.

Prof Mohareb believes that the main issues architects face when dealing with fire engineers is the fact that the two professions have different priorities, and thus each of them lack flexibility in their requests and designs, as they believe that their priorities are more essential than the others'. He recommends the implementation of a clear but flexible fire code which is understandable by professionals from various disciplines and can be easily applied to different situations. He also reckons that a fire safety engineer should be part of the design team as soon as the conceptual project idea is finalized, for maximum efficiency.

5.1.2. Dag Leyre Olsen

Dag Leyre Olsen was contacted as being an architect with an extensive experience in fire safety issues, as to enquire about his opinions about the relationship between architects and fire engineers. He is a Sivilarkitekt MNAL and has been part of "Niels Torp Arkitekter AS" since 1995 and is the author of "Brannteknisk Prosjektering" in 1998.

Upon being asked about architectural education in terms of fire safety issues, Dag answered that when he was a student, he only received about 4 hours in lectures related to fire safety within all his study years. He believes that fire safety needs to be integrated in all architectural work in order to achieve an efficient working system. Within that, architects must have full control over their whole design, starting from the conceptual part all the way into the detailed execution design, in which fire safety is embedded throughout, beginning from the first concept. However, as creating the design concept is solely the architect's responsibility, it's essential to equip those architects with the main principles of fire safety as such knowledge will allow them to have qualified dialogues with fire safety engineers.

Personally, Dag Leyre Olsen always tries to engage a fire safety engineer as soon as the project concept is initiated, mainly to ensure that all solutions can be well documented, and perhaps try to avoid future modifications to the architectural design. Even though the fire engineer will have the highest workload in the early phases of a project, they should maintain follow up until the final stages, to ensure the effective implementation of their solutions. Moreover, he reckons that it's essential for fire engineers to be able to read, understand, and grasp drawings from an architectural perspective. This will result in them coming up with specific solutions tailored specifically for each building, rather than blindly applying rules and regulations and prescriptive solutions. Though deviation analysis might be a time-consuming process, it definitely provides architects with additional flexibility in their designs.

On the other hand, Dag Olsen suggested that, to enhance the current system, architects should be equipped with increased qualifications that will allow them to understand fire, both within their studies and their professional lives. That mostly applies to understanding concepts of fire sectioning and compartmentation, as well as methods of creating safe escape routes.

5.2. Landscape Architects'' Views

Within the landscape design phase, additional details for the site plan and landscaping are specified, including water supply locations, firefighter's access routes and their dimensioning, and possible blockages and alternatives of those. It is also considered that building ornaments, sculptures, and vegetation would not add up to existing fuel amounts, ignition possibilities, or hinder evacuation or emergency response.

Ekuko Naka, landscape architect at Sweco, was interviewed for this part. Several examples were discussed in which Sweco was handling the landscape design of projects, and challenges were defined accordingly. There were a couple of defined problems which indicate that fire engineers don't fully understand the work of landscape architects, or at least they don't try to understand it enough.

According to Ekuko, the phase in which a fire engineer is usually introduced varies from a project to another, in which it could be as early as in the conceptual phase. However, the landscape architect is mostly introduced at a much later stage, and thus has to deal with the design solutions that have been placed by the architects and the fire engineers, in which the architects have responded to the requirements of fire safety performance, and sometimes that can be quite difficult.

5.2.1. Different Understanding of Concepts

To begin with, it was mentioned that fire engineers, when they're formulating the fire concept after the architectural design phase of the project, resort to merely drawing rectangles that refer to where the fire trucks will be parked, without considerations to its way in and out (including distances and turning radii). Figure 5 shows an example of that, in which a site plan of a housing project (copyrighted to Sweco AS Norge) was edited by fire engineers. According to the regulations, the fire engineers added the supposed locations of the fire trucks (shown as red rectangles), without any consideration for how they are supposed to get in and out.

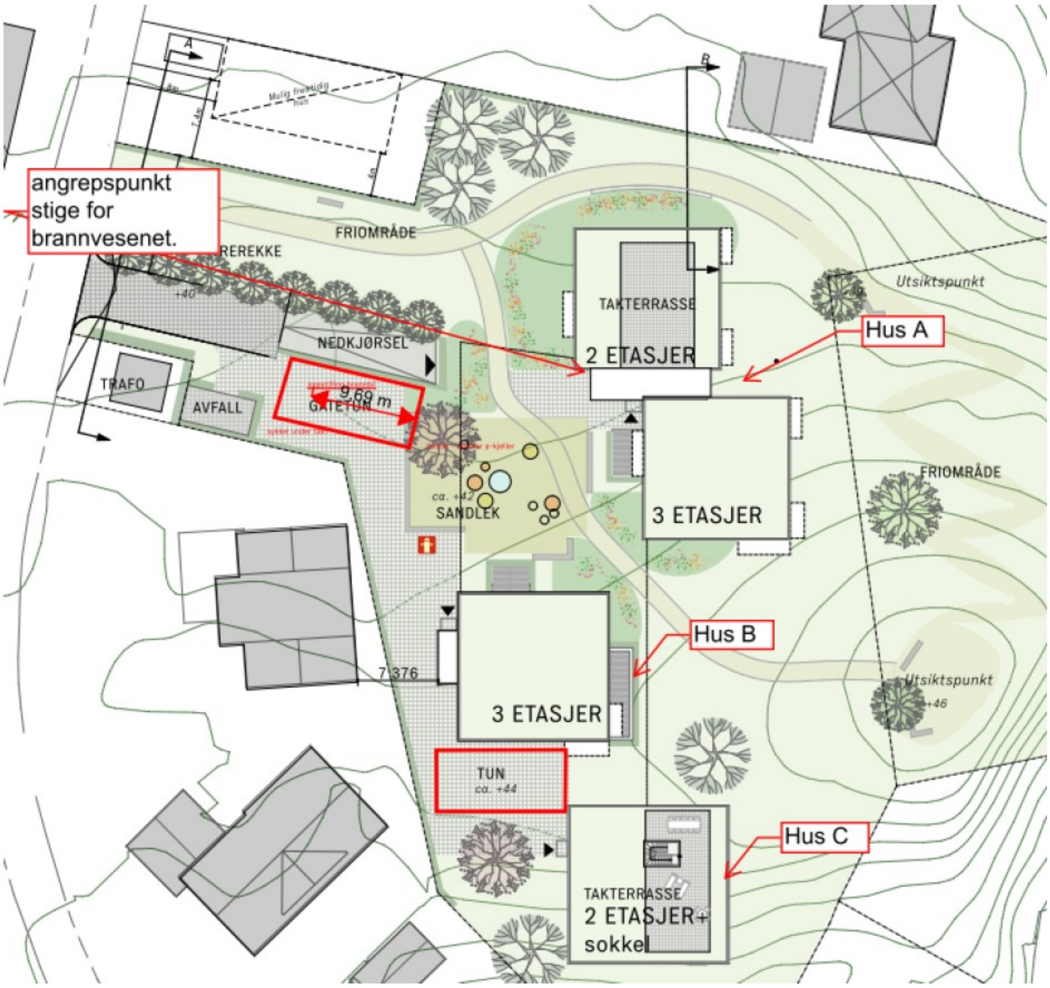

Figure 5 Site Plan (edited by fire engineers) to show the proposed location of fire trucks

Afterwards, the landscape architects are required to amend the design and complete the drawings based on that. Though fire engineers can sometimes have extensive dialogues and discussions with architects, they rarely check with landscape architects on various design aspects and how that would affect the fire concept. Because of the fact that fire trucks are large and require specific aspects in terms of allocated free space (that doesn't include any ornaments, furnishings, vegetation..), floor grading, distance to surrounding areas, and such, the most effective solution would be to design those features as early as possible into the design phase. When that's not done, it poses major issues for landscape architects specifically to find effective solutions for those fire truck spots later into the project.

Moreover, the specific requirements for water supply and fire hydrants pose a challenge for landscape architects for accommodating the municipal regulations while still managing to create functional and aesthetic surrounding environments for projects. In addition to that, materials need to be well selected to ensure their fire resistance characteristics as well as their strength in handling both fire and the load of fire trucks, which almost always incurs high financial costs.

5.2.2. Different Priorities

As with the case of design architects, the issue of different priorities pops up when discussing the fire engineer/landscape architect relationship. According to Ekuko, the landscape architect is capable of seeing the whole picture, while the fire engineer only addresses the elements that matter to him/her, from a fire safety perspective, thus offering much less creativity and innovation.

An example of that can be seen in the following project, as we can see the difference in how the fire engineers and landscape architects "think" and convey their thoughts accordingly. Figure 5 shows the site plan from a fire engineer's point of view. The fire exits are clearly located as well as the location and orientation of the fire trucks.

Figure 6 Floor Plan of the building with fire measures – Drawing Copyright to Sweco AS Norge

However, the landscape architects had to amend the drawings issued by the fire engineers as they had a lot more variables to consider. Figure 8 shows how that was done to include the turning radii needed by the fire trucks, as well as the location of the trash cans (highlighted in blue at the right of the drawing), which would in turn affect the location of the fire trucks. Moreover, Figure 7 shows the location of the water and gas pipelines, the HVAC connections, and the line of trees required by the regulations on the neighbor border. All of these issues would undeniably affect the proposed fire plan.

Figure 8 Site plan including the turning radius - Drawing Copyright to Sweco AS Norge

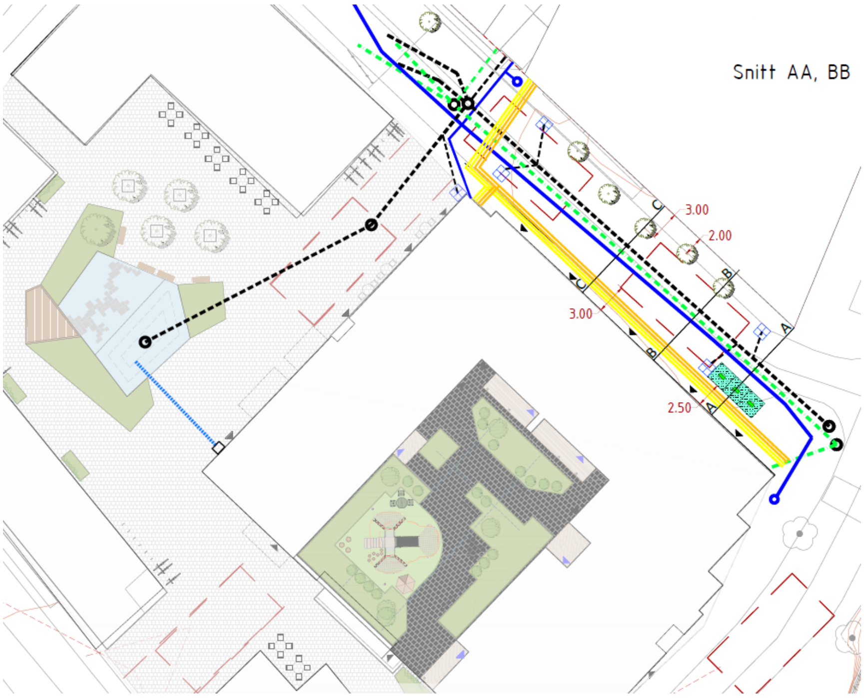

Figure 7 Site Plan showing the water supply, piping, among other landscape issues - Drawing Copyright to Sweco AS Norge

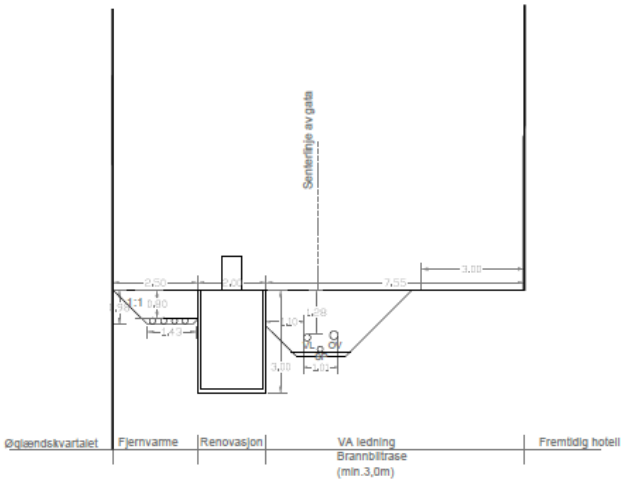

Figure 10 Section A-A

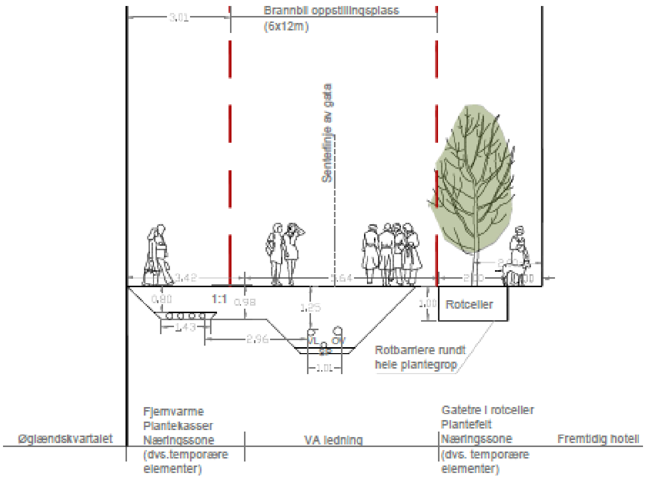

Figure 9 Section B-B

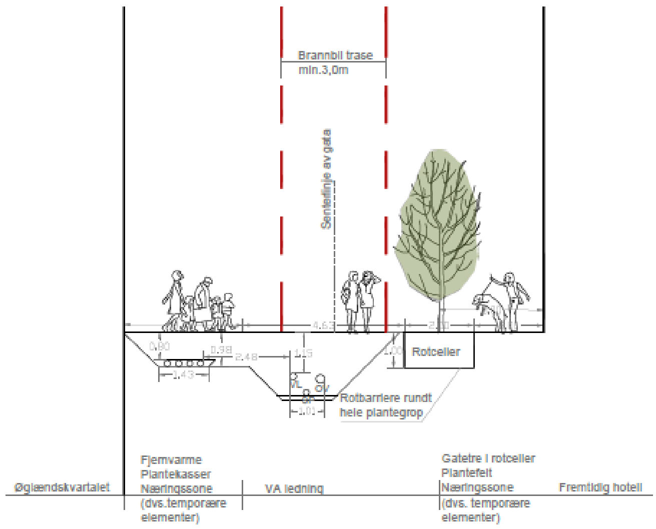

Figure 11 Section C-C

This is better shown in the cross sectional drawings (Figure 10, Figure 9, and Figure 11), which explain the areas required for the fire truck and the corresponding piping and landscaping elements that need to be considered. Figure 10 also shows the garbage containers that are embedded in the ground, which also hinder the placement of the fire trucks above the area. Such issues are what make it essential for both fire engineers and landscape architects to be able to see the whole picture when designing, which would in turn lead to much more effective design and collaboration process.

Moreover, seemingly, fire engineers usually have continuous dialogues with architects from the early phases of the project. These dialogues aim at adapting the placement of the fire trucks and their different types (crew or ladder trucks) according to entrances and such. However, they don't have the same dialogues with the landscape architects who are in fact responsible for those issues.

Nevertheless, Ekuko mentions that fire engineers can be quite accommodating when asked to perform certain changes to better fit landscape requirements. Though, if they had thought about things a bit more creatively, those aforementioned issues could have practically solved themselves.

5.2.3. Regulation Issues

Recently, there has been several changes to requirements related to fire trucks and their access. For example, both Stavanger and Sandnes municipalities have now obtained bigger fire trucks. Consequently, the access routes and turning radii of those routes need to be modified accordingly, putting even bigger pressure on landscape architects. Even considering that the smaller trucks can be fit in a certain project, the possibility that those trucks are at another incident must be taken into consideration, and thus the design must be handled accordingly.

Moreover, and in certain areas of residential nature, especially older zoning models, the types and widths of roads are not constructed in a way which can handle the new additions to the fire-fighting technologies, in terms of trucks and their requirements. Thus, the dimensioning of certain complexes within such areas becomes quite difficult, if not almost impossible. Urban zoning regulations should be able to take such matters into consideration.

5.3. Fire Safety Engineers' Views

5.3.1. Consultancy-oriented

After speaking to several fire safety engineers from various experience levels, they agreed that one of the main problems with architects is the issue of priorities, as it seems that they can sometimes value aesthetics more than safety. Moreover, some architects lack an understanding of why the fire engineer needs to perform a fire analysis when the pre-accepted solutions are not met. Furthermore, they fail to see how their design choices affect fire safety and the consequences they have.

One of the most common issues is that related to the choice of materials, especially those in escape routes. Deviations on this matter are widely applied, mainly because architects do not prioritize fire safety over aesthetics. Nevertheless, many architects are quite familiar with the pre-accepted solutions and design accordingly, especially when it comes to evacuation routes' width, numbers, and such. Yet, they usually lack the necessary knowledge when it comes to special circumstances (atriums, open areas, half stories, etc.), especially since they don't fully comprehend the legislation documents, which can be deemed as a bit complicated for non-professionals. This can sometimes result in requiring an extra staircase or additional barriers in these areas, especially when the fire engineer is introduced later in the project phases.

Moreover, even though architects tend to have some flexibility issues when dealing with fire safety engineers, a compromise is usually reached, especially when both individuals are experienced. Yet, the fact that there is no control or supervision after the fire concept is put in place can prevent errors from being registered. This aspect is mainly noticed in terms of finishing materials and furniture installations especially in escape routes.

Morten Iversen Berland, a fire safety engineer at COWI with over 11 years of experience from various companies, states that the role of a fire engineer exceeds just developing the fire strategy of building, but rather they should be part of the detailed engineering and construction phase, all the way into the finished product. He mentions that the construction industry needs more competence in how the fire concept is developed, and thus the fire advisor needs to acquire new roles.

Morten considers that the fire engineer should become a tool for proper communication, management, execution, and quality assurance, in order to reach a successful (from a fire safety point of view) project. He reckons that fire protection of a building exceeds issues of fire detection and extinguishing systems, or other engineering installations. It is also included in the organizational and architectural aspects, as each element can have a direct or indirect impact on the others and should act in complementary manner to constitute an effective fire protection.

However, to achieve this goal, it is important to establish effective communication between the various actors as early as possible during the detailed engineering and construction phase. The purpose must be to educate all parties about the way various measures interact to eventually constitute the holistic fire safety concept. Design decisions taken by one of the individual actors without consulting the others, or at least understanding the aforementioned interaction, can almost definitely cause issues during the completion and the operational phases. This can also lead to the failure of the planned fire safety. Such a situation is unfortunately common and can lead to delivery and/or documentation delays, and consequently, a significant increase in costs.

Thus, preventing such errors is crucial. Until the Norwegian building authorities introduce such requirements, maybe following the lead of the Danish authorities, the building owner/builder and their advisor (architect) must be fully conscious of their responsibilities. This would mean requiring that the fire engineer is involved in the whole process, from A to Z. This would eventually form a basis for an effective communication with governments, contractors, insurance companies, engineering systems suppliers, and other stakeholders. It would be a successful investment, eventually reducing the risk of fire and limiting its consequences, thus ensuring proper delivery and savings on life cycle costs. (Haug, 2019)

5.3.2. Fire Research – oriented

The below has been acquired by researching some literature as well as conducting an interview with Dr Kathinka Leikanger Friquin, a research scientist at SINTEF in the department of Architecture, Materials, and Structures. We will first begin with an introduction of SINTEF and the work they do in fire safety and then move into discussing the viewpoints presented by Dr Kathinka.

SINTEF is one of Europe's largest independent research organizations. Every year they carry out several thousand projects of various scales for customers. One of the branches they specialize into is fire safety, through offering research-based consultancy, calculations, analysis, and assessments to ensure that fire safety solutions in buildings comply with regulations and standards. (SINTEF, 2020)

5.3.2.1. Priorities

When asked about the different priorities of each of the parties involved in a construction project, Dr Kathinka expressed that due to her experience, architects are mainly concerned with aesthetics, usability and flexibility. However, stakeholders are mostly concerned with financial issues and turnover rates, thus focusing on the abundance and types of usable space, as well as maintenance costs. Some of them also focus on fire safety, as they're aware of the financial costs in property damage as well as human safety. As for building authorities, the safety of people of of utmost importance, followed by protection of values and assuring that fire spread is contained.

Moreover, contractors are driven mostly by financial requirements and cutting costs for both materials themselves and their mode of construction (need for specialized workforce, difficulty of execution, maintenance, etc.). As for manufacturers of building materials, and since SINTEF handles a lot of work involving them, it's known that they need to develop products that have high demand in the market. Thus, their products need to have competitive prices, high accessibility, innovative, and easily installed. Yet, their focus is on properties that are obvious to the buyer, and not all of them have the necessary knowledge about the properties of their products in terms of fire safety. Some of the larger manufacturers even have their own test laboratories.

As for fire engineers, fire safety is their utmost priority. That is achieved through the types of materials used, escape possibilities for people, access for fire services, and such. Thus, they need to follow the building regulations to achieve the highest possible level of fire safety.

5.3.2.2. Knowledge levels

Dr Kathinka mentioned that architects have limited knowledge regarding fire resistance of materials, though they are one of those mainly involved in choosing said products. Also, they tend to resist changes to those materials as that might affect the general aesthetics of the project.

However, manufacturers often possess a high level of knowledge about the fire resistance properties of their products, and some might even have adequate knowledge about testing processes and required fire properties. Yet, they don't appreciate changes in regulations and standards as that usually incurs additional fees and might consequently affect their sales.

As for importers, they possess even lower levels of knowledge about their products, as they are usually minorly affected by changes. Dr Kathinka stated that they are faced with lots of various parties who lack the necessary knowledge to be able to effectively choose the correct materials, and to consequently understand how changes to those can affect the fire safety requirements. Unfortunately, the lack of knowledge is quite widespread.

As for the introduction of new construction materials and building systems, the amount of knowledge varies greatly. Some fire engineers try to keep themselves updated with the characteristics of these materials, through reading research and experiments. Producers need however to keep themselves up to date to make sure that they're able to develop their products according to the newest standards.

5.3.2.3. Standards and Regulations

When asked about the rate at which standards are being amended as a result of new fire research and testing, Dr Kathinka mentioned that it happens usually once per decade, as they're revised at a European level. However, even though the Norwegian regulations are not updated very often, the guidelines are revised regularly, even to offer minor changes or clarifications to already existing points.

As for the participation of SINTEF in the development of standards, Dr Kathinka mentioned that it's done at SINTEF's own costs, as the government doesn't offer funding for that. As mentioned before, Norwegian standards are governed by European standards, and thus, amends to those must fulfill testing and research from various manufacturers, at their own cost. This leads to some resistance from producers due to high incurred costs. Moreover, construction styles vary from one European country to another, but the standard should be able to cover them all. For example, a certain glazing product in Spain needs to fulfill properties of climatic features that are not required in Norway, and vice versa. This could lead to a choice of declaration of certain properties in Spain that does not fit Norwegian requirements.

5.3.2.4. Assessments, control, and supervision

When conducting 3rd party assessments, Dr Kathinka mentioned that disagreements mostly stem from incorrect interpretation of the test methods and classification standards, or of building regulations. Those assessments are usually performed during or after construction, so based mainly on built solutions rather than documents when it's due to a disagreement among parties. However, if the assessment is related to the issuing of product documentation, then it will be performed during the pre-construction phase through evaluating the fire performance stated in the product documentation.

As for the control and supervision, Dr Kathinka stated that it would be beneficial to conduct supervision on products themselves rather than just the process, to ensure that the construction is handles according to plans and standards, and that the fire specifications are not compromised during construction.

As a general conclusion, it was discussed how the fire engineer's role is limited to stating the relevant building regulations and fire characteristics needed for a specific project. However, other players (mainly structural and civil engineers and architects) would choose the actual materials and products to be used. This includes but not limited to designing fire resistant walls and windows, finishing materials, load bearing characteristics, as well as structural integrity. This would highly limit the involvement of the fire engineer and can thus jeopardize the project as whole, from a fire safety point of view. This leads to the conclusion that having a fire engineer in place during all different phases of a project can prove to be advantageous.

5.4. Conclusion

As we can conclude, an architect’s knowledge about fire safety, whether regarding the main concepts of fire (heat release rate, flashover concept, smoke and its control, etc.), or regarding active and passive fire safety measures, is somehow limited, though it can vary extensively depending on the personal professional experience of each architect.

The above can be due to several reasons. On one hand, in order to achieve a successful design that “ticks” all the boxes (as shown in Image 1), the architect must consider different priorities and a huge number of various requirements, which in turn can take a major toll on his/her mind thus shaping the design differently than an engineer would. This can sometimes lead to disregarding, whether intentionally or unintentionally, some fire safety requirements. On the other hand, however, it might be simply because architects lack the basic education on those issues.

The solution that need to be reached should be one that suits the architect, the landscape architect, the fire engineer, the water engineer, and the civil engineer, among others. And that’s never an easy job.

This brings us to the next chapter; What do architects learn about fire safety in various architecture schools? International, Norwegian, and Lebanese schools’ curriculums will be further studied and analyzed in the next chapter.

6. Architectural Education

As studies have revealed that building designs can highly affect the magnitude of fire spread within a building with severe consequences on life and property, architects should seek to fulfil fire safety considerations at early design stages. Appropriate knowledge of fire safety can help in creating fire safe buildings.

To understand how architects perceive fire safety design, we need to comprehend the education they receive at the university level. The discrepancy in priorities should be addressed, as a way to eventually reach common grounds between the two professions.

Thus, this chapter explores what architects learn about fire safety in various schools of architecture internationally, in Norway, and in Lebanon. This chapter will thus help in pinning the problems that architects face in terms of knowledge of fire safety requirements, hereby questioning the efficiency of that education for creating fire safe buildings.

6.1. International

Looking at different schools of architecture, we can conclude that (at least as a general conclusion) that there are no specific courses dedicated to teaching architects about fire safety. However, such knowledge is acquired through topics embedded within other courses. A study conducted by (Ebenehi, Ruikar, Thorpe, & Wilkinson, 2016) through holding several interviews with educators and practitioners has revealed that there might not be a need for a separate module that teaches architecture students about fire safety. However, most of the participants indicated that job training and continuing professional development is essential for that domain to enhance the graduates' knowledge of fire safety requirements. Education at the university level is able to provide the fundamental knowledge and skills, and students are told to seek help when necessary, mainly from fire engineers. It was also mentioned that practicing architects have the sufficient knowledge of fire safety, acquired from experience, and they're willing to engage fire engineers especially for complex design projects.

6.2. Norway

6.2.1. UIS – University of Stavanger / *Universitet I Stavanger*

Though the University of Stavanger does not offer a degree in architecture, they do offer ones in Construction Engineering and Urban Planning within the Faculty of Science and Technology, Department of Mechanical and Structural Engineering and Materials Science.

The course which touches on the issue of fire safety is titled "Construction Physics and House Building". Through this course, students gain fundamental insights in building physical topics as: weathering and local climate, indoor environment, **heat engineering building design** and calculation of **energy**, moisture mechanics, sound, lighting and **basic fire theory**. Students acquire a broad understanding of the technical challenges and solution principles for ordinary wood houses, foundations (terrain, soil conditions), structures, exterior walls, windows and doors, roofs, interior and technical installations, special rooms, and outdoor spaces. They will also acquire some basic knowledge of materials used in construction projects, including their properties and applications.

Students should have prior basic knowledge about building in Norway over the past generations and be familiar with the applicable **technical regulations (TEK17)** including requirements for universal design and other relevant **laws and building regulations**. (Institutt for sikkerheit, 2019)

6.2.2. BAS - Bergen School of Architecture/ *Bergen Arkitekthøgskole*

There isn't a fixed curriculum on fire safety engineering at BAS. However, much of the teachings are linked to the studio courses where students are supervised in accordance with their project assignments and where the question of fire safety is taken up for discussion. Issues such as ensuring door blade direction, window placements, width and length of corridors and so forth are discussed in various tutorials during drawing floor plans. For more detailed knowledge, the students are taught to depend on consultancy from a fire safety engineer. Moreover, fire safety is addressed in material workshops in the 2nd grade, and in real commissions when students are required to build full scale pavilions and buildings. Then, they are put in contact with engineers to create properly approved holistic projects. [1]

6.2.3. NTNU – The Norwegian University of Science & Technology/ *Norges Teknisk Naturvitenskaplige Universitet*

Within the degree of Architecture offered by NTNU, students are exposed to the concept of fire safety within two courses. The first is "Building Physics for Architects", which introduces indoor and outdoor climate, heat transfer including introduction to energy use in buildings, moisture transfer, acoustics and lighting. Students learn to evaluate buildings against the Norwegian Building Code and carry out basic heat transfer calculations in order to find the thermal resistance and transmittance (U-value).

The second course is "Architectural Design of Large Buildings" in which students learn about building structures and construction, building materials, technical infrastructure, water, lighting, heating and acoustical environment. They are also introduced to building regulations, as well as fire and security precautions. (Studiets oppbygning - Masterprogram 5-Årig, 2019)

[1] Retrieved through contacting the school

6.2.4. AHO – The Oslo School of Architecture & Design / *Arkitektur og Designhøgskolen I Oslo*

Nils Forsén, a professor at AHO (Oslo School of Architecture & Design) with over 25 years of experience in architecture and civil engineering, is the one responsible for teaching AHO architecture students about fire safety issues. 2nd year Students spend around 2-3 hours on lectures related to fire safety, in which they are then required to apply their learnings within their architectural design studios. At various points of their education, their fire safety measures are questioned in those studios, and the designs amended accordingly; "Learning by doing" as Professor Forsén refers to it.

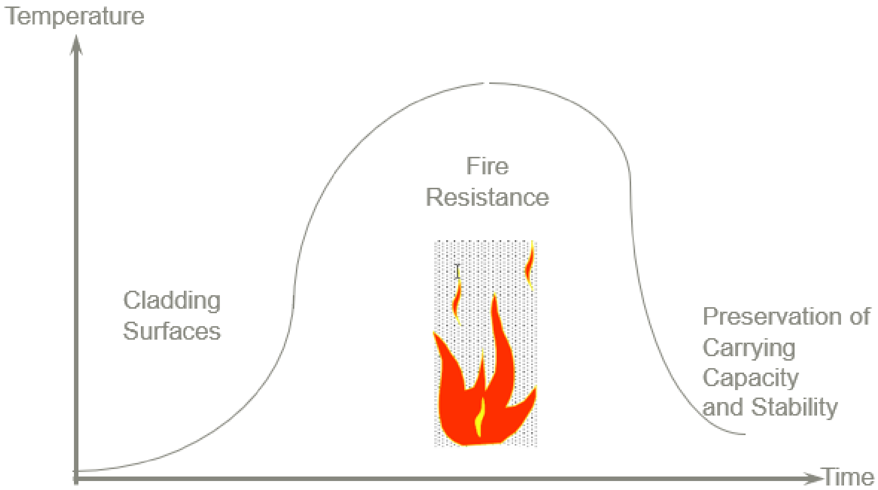

Figure 12 Showing the responses in various fire phases

The lecture[1] offered to students as part of a course titled "Architecture and Climate" starts by explaining fire as a phenomenon and listing some major historical fires and their respective effect on the laws and regulations, along with some statistics of Norwegian fires and their death tolls. Then, fire phases are explained (ignition, fire development, flashover, steady phase, and cooling/burning out).

Within each phase, the role of the architect is clarified, with the emphasis on early phases as the architect would be the one responsible for choosing cladding surfaces and finishing materials, which in turn could either highly contribute to the fire or hinder it. Figure 12 above explains the factors that are at play during various phases of fire development.

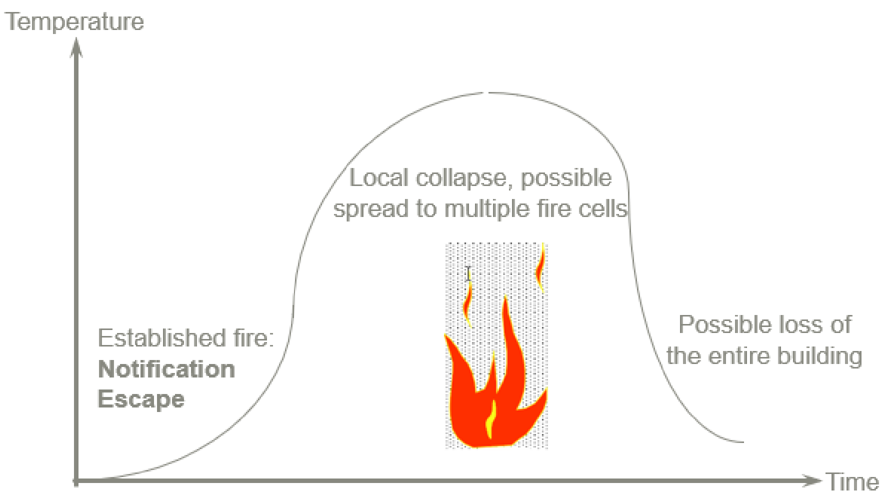

Figure 13 Showing the various possible scenarios

[1] The lecture presentation was retrieved and explained by Prof Nils Forsén himself. All the figures listed are either kept in their original language (Norwegian) or translated to English

However, Figure 13 shows the possible scenarios, in which notification and escape would take place during the first phase, which emphasizes its importance.

Moreover, Prof Nils proceeds to explain how the regulatory system works, on the political, technical, and market levels. Figure 14 below explains how the political level is the one responsible for laws and regulations, thus producing a certain number of pre-accepted levels of performance that the building can be measured against. Consequently, the technical level provides standards containing detailed instructions. The market, however, delivers technical approvals and certification through various organizations and guidelines. Documentation is an essential step throughout all levels.

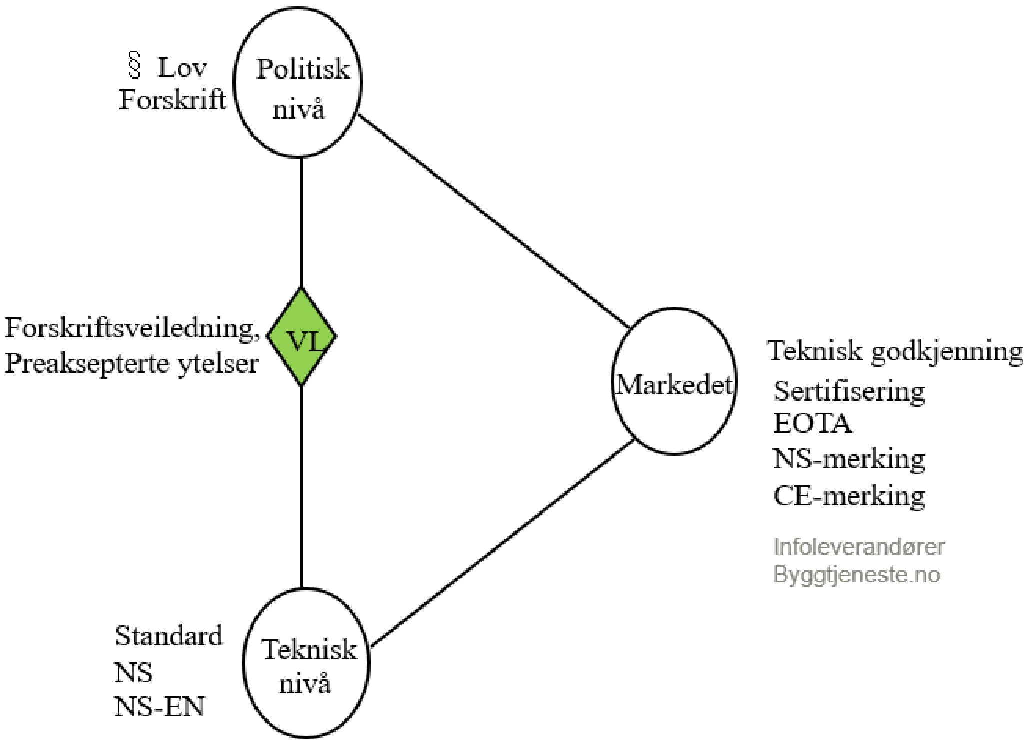

Figure 14 Showing the Regulatory System in Norway

Afterwards, the lecture explains the importance of an architect's insight into the fire theme, especially during the early stages of architectural design. Its criticality exposes itself in the form of organizing volumes (and fire sectioning/compartmentation) and limiting evacuation distances. Then, risk classes and their respective maximum evacuation distance are listed. However, it is here mentioned that respective analysis might be able to allow for increased distances.

Furthermore, fire strategies are discussed in terms of various methods of active and passive fire protection, along with the organizational and technical factors controlling that. Here, the students are equipped with websites detailing all those issues and acting as a reference for them to use when designing. Requirements of specific building use, number of floors, and fire classes are mentioned as affecting the decision on a certain fire strategy.

Students are then introduced to the functional requirements of TEK17, fire classes, and the consequences of a collapse; focusing on load bearing capacity and structural integrity required of different classes. This is further emphasized through Fire Resistance Classes (R-Load Bearing Capacity, E-Integrity "Flame and Smoke Resistance", and I-Insulation). Additionally, the concept of compartmentation is presented in terms of fire cells and sections and their effect on fire spread, along with required distances between buildings, followed by escape routes and their requirements.

6.3. Lebanon

6.3.1. American University of Beirut

The architecture program at the American University of Beirut focuses mainly on the "design and aesthetics" part of architecture, with some minor focus on the technical part. In their third year of studies, students are introduced to various building systems, within an "Environment" focused course. Within that course, they go through a design-oriented study of environmental control, life safety and building service systems; consisting of electrical, lighting, heating, ventilation, air-conditioning, water and waste, acoustics, fire safety and fire protection, and vertical transportation. The course covers basic principles, applications and performance of environmental control systems, and addresses these systems as they impact building planning and design, and occupant health and comfort.

Moreover, in their fourth year of studies, and within their architectural design studio (the major and most credited course, repeated across all 5 years of the bachelor studies), students apply the knowledge and skills acquired in all previous design studios, theory and technical courses. Projects envisioned are complex building structures addressing the public domain, circulation, accessibility, life safety, parking, building codes and zoning regulations. In this course, they get to apply all they have previously learned, including fire safety issues. [1]

6.3.2. Beirut Arab University

The faculty of Architecture- Design and Built Environment at Beirut Arab University is that responsible for providing degrees in Architecture. However, there are no dedicated courses within those programs (whether in the bachelor or master programs) that teach fire safety to students. Nevertheless, this is somehow compensated by hosting public lectures regarding that matter, but which are optional to attend, as well as mentioning the matter in some courses such as structural integrity, HVAC, and building regulations issues. Moreover, tutors tend to somehow regard safety issues within design studio courses, but from a rather broad perspective, and out of professional experience not educational ones.

Prof. Nabil Mohareb, Dean of the Faculty of Architecture, Design, and Built Environment at BAU/ Tripoli branch stated that the amount of knowledge students receive about fire safety depends on how their entire study program is steered. That is, if the architectural study is within the fine arts or humanities scope (as is the case for several universities in Lebanon), it is better for the student to receive general knowledge allowing him/her to understand the current system related to fire and their importance accordingly. However, for those majoring in architectural engineering, it should be one of the mandatory topics and addressed as one. Currently, Prof Mohareb believes that graduating architects possess a sufficient amount of knowledge regarding fire safety. He thinks that all they need is having a working knowledge to discuss and implement the systems with other experts in the field, rather than having to study the complex detailed firefighting systems.[2]

[1] Retrieved from the university's website and by contacting faculty members
[2] Retrieved by contacting Prof Nabil Mohareb

6.4. Conclusion

As a conclusion, we can see that architecture curriculums in both Norway and Lebanon somehow lack the sufficient amount of fire safety knowledge, even though this part is gaining increased importance, while of course considering the differences between various universities and countries. The fact that energy, sustainability, and climatic issues are being addressed more often is positive, as they can mostly incorporate fire issues as well.

Therefore, maybe it's a good idea to introduce some major fire concepts that architects usually do not understand within architectural education. This could primarily include the Heat Release Rate concept, which would eventually get them to comprehend how quickly a fire can develop and how much heat it produces within that time. The concept of a flashover would also be very important, as well as the smoke layer height and its effect on occupants, toxicity levels, and the effect of ventilation and turbulence. Since architects are usually the ones who choose different construction and finishing materials, it would be beneficial if they knew how different materials react to fire, especially their structural stability and the rate at which they burn.

Nevertheless, the priorities of architects will always be motivated by their artistic inclination, in which various engineering disciplines are regarded as constraints rather than possibilities, and this will continue to create controversy.

However, that discrepancy in priorities can result in catastrophic consequences. As the architect/fire engineer relationship is not that well-defined, the responsibilities of each of them can somehow be unclear. Though less occurring, an architect might in certain cases be responsible for handling the fire safety in projects, especially smaller ones. And mostly, the architectural design of a building will most definitely influence its fire safety performance, mainly in terms of passive fire protection. Consequently, a lack of knowledge from the architect's part accompanied by a low involvement from the fire engineer's part can cause the building to behave poorly in the case of a fire.

Could that be avoided? How? The next chapter will illustrate some case studies that further elaborate that concept.

7. Fire safety Education

To understand how fire engineers perceive architectural design we need to comprehend the education they receive at the university level. The discrepancy in priorities should be addressed, as a way to eventually reach common grounds between the two professions. The below will discuss the education of fire engineers internationally, in Norway, and in Lebanon.

7.1. International

According to SFPE (University Programs - List of Schools, 2020), there are currently 28 universities around the world that offer Bachelor of Science or Master of Science degrees in fire protection engineering. Upon looking at several of those schools, the main thing they have in common is that they all try to expose the fire engineer to an environment that tackles a multidisciplinary approach to the profession. Nevertheless, that part is mostly practical, as students don't get a chance to apply that approach, even within the internships that some of them are required to go through. Some of the students are lucky enough that they manage to secure internships at bigger firms that already have different types of engineers and designers within the same office, and thus get to work with those, but that's not always the case.

7.2. Norway

The Western Norway University of Applied Sciences (HVL – *Høgskolen på Vestlandet*) is the only university in Norway that offers a bachelor's and a master's degree in fire safety engineering. The 3-years program leads to a bachelor's degree, which can be followed by 2 years for an MSc. It's an engineering degree with a heavy emphasis on safety studies.

This program was first initiated as the need for more focus on fire protection and safety was becoming eminent in the society. The fact that tunnels were becoming longer, buildings higher, and offshore installations more complex provided exciting challenges that needed to be tackled by fire engineers. According to HVL's website, the study at this program is interdisciplinary with central themes revolving around fire physics, risk analysis, active and passive fire safety, emergency preparedness, and building technology. (Study plan - Bachelor in Fire Safety Engineering, 2019)

Upon graduation, the student should have a broad knowledge of the holistic perspective to the engineering field and has the proper tools to upgrade his/her knowledge according to the new developments that may take place in the field. The graduate should also possess the necessary skills to work within a team that includes various disciplines, from both engineering and design fields. This requires them to be able to communicate their knowledge to other key players in the project, including architects and designers, in which they'd need to use a suitable scientific language and terms that they can both understand.

Though, theoretically, the study program should prepare the fire engineer to work in a multidisciplinary environment of both designers and various types of engineers, the lack of specific required internship leaves that part up to pure chance. Some students will actually get the chance to work in such an environment and thus learn those skills, while others won't.

7.3. Lebanon

Unfortunately, Lebanon does not offer any degrees in fire safety or fire protection engineering. Most of the fire engineers who work in Lebanon have acquired their degrees abroad. Others have based their work on experience and reading and application of available standards (SFPE, NFPA and the French norms are those accepted in Lebanon).

8. Control & Supervision

As there are already issues between architects and fire engineers, one of the solutions might be to offer adequate control and supervision to various projects, which could in turn help in the early discovery of errors, and thus offer the chance to correct them before it's too late. The below will only be discussing the control and supervision issues in Norway, as it was difficult to get a hold of information from other countries.

The building details criticized in Mæla School (refer to 9.2.1) were not about the design group's designed solutions, but about built solutions, which is a contractor's responsibility. This raises several questions regarding control and supervision, throughout various design stages. Could the issue have been avoided if the built solutions were controlled? There is a critical difference between the design solutions which are mostly controlled and the built solutions which are mostly uncontrolled. This chapter will further discuss that issue with regards to Norway rules and regulations specifically.

Before 1997, building authorities had a far more active role in assessing and approving fire solutions. However, afterwards, competence requirements were set, and the fire advisor role gained more importance. One of the special competences was that of fire safety engineering, which was previously handled by the architect and various specialist advisors. Thus, starting 1997, qualified fire advisors were required to perform those tasks. (Ulfsnes & Danielsen, 2004)

The product from the fire advisor was usually a performance description report (referred to as Fire report, fire strategy, fire technical concept, etc.), which summed up the governmental requirements from the Plan and Building Act and the technical regulations. This mainly demonstrated how the fire escape routes and the defined fire performance were to be performed, often acquired from the guidelines. As such a fire concept will act as the basis for the detailed design, a prerequisite must be that its users can fully understand and perceive the specified performance requirements and assumptions applied. If those assumptions were overlooked, regardless of the reason, wrong solutions might be selected, solution that would affect the overall fire safety of the building.

Previously, the role of the fire engineer was limited to developing the aforementioned document, with minimal involvement afterwards. Now, however, his/her responsibility is defined within the contract and presumable should cover the entire construction process. Those handling the detailed architectural design should make sure that it meets the performance requirements of the fire concept. Any deviating solutions are to be treated as discrepancies, documented, and eventually reviewed with the fire strategy. Unfortunately, special fire objects are the only ones which require supervision of the fire documentation in the operational phase. However, the contractor/entrepreneur's responsibilities are specifically high in Norway, and their extent usually depends on the form and size of the construction. Solution selection is part of the design process, which should not include the contractor. Nevertheless, it is still practiced that the executing party (the contractor) will choose some documented solutions or amend them during the construction phase.

Control and supervision, whether internal or assigned to other actors in the form of independent control, is essential. When holding an entity responsible for conducting control, it is assumed that they possess quality assurance systems that maintain control in a satisfactory manner. All control within a specific area of expertise should abide by the local building authority regulations through verification declarations. Though local authorities have the right to supervise construction issues, such supervision is usually limited to control of the systems used and comparing them against the requirements. Moreover, audits performed are against documents, and rarely against actual constructed solutions.

8.1. Errors – Where and When?

In several construction projects, there is a certain vagueness about the party responsible for protecting fire safety across various disciplines and controlling the difference between the designed and the executed projects. Failure to clearly determine and distinguish that responsibility almost always will result in poor communication of fire technical issues among disciplines and their respective actors.

Errors can occur throughout all phases of constructions, early and late ones alike. Early errors in the conceptual performance phase can occur and remain undetected, and later constructed into physical solutions that do not confirm to the performance requirements. For example, when choosing the fire classes and risk classes, it's essential to consider flexibility of future changes and possible modifications of the building use. However, it is the architect/designer's responsibility to project future changes in their original design so that the fire engineer can design accordingly.

The establishment of satisfactory escape routes is of utmost importance in regulations. However, mistakes are common in that area, whether due to the design itself or the choice of finishing materials. In cases where deviations from prescriptive solutions need to be made, the transition to performance-based regulations has caused problems for both the executing and the building authorities.

Moreover, as following fire regulations assumes the proper equipment and staffing of the fire brigade, the choice of fire solutions should be able to assess the capacity of the local fire brigades, especially when it's given a major role in the extinguishing and escape requirements. Another issue would be the access given to the building itself.

8.1.1. Why do errors occur?

Construction projects are often characterized by time constraints, demands for financial control, and the pressure executed by the contractor/entrepreneur especially against subcontractors – there is always a need to cut costs somehow. Usually, the design and solution choices must be taken care of by the engineering group, the entrepreneur or contractor should not be allowed to make decisions on engineering solutions. However, in certain types of contracts, it is accepted to make certain redesign decisions provided that the delivered/built result satisfies the requirements of the rules and regulations. In such contracts, it would be very important to document all the chosen solutions that are deviated from the original.

A prerequisite for a successful collaboration among actors is that everyone should be well acquainted with the fire strategy and the background behind each of the choices and solutions made.

Moreover, insufficient traceability in the fire technical documentation is a problem that usually becomes evident where supervision takes place. In several cases, building authorities have uncovered inadequately documented solutions. However, supervisory authorities don't always have the necessary skills to point out errors. Traceability is also essential to check and ensure that someone's own design and solutions – whether at the design or execution level – abides with the current prerequisites, rules, and regulations. An adequate level of traceability assumes that the documentation is deemed satisfactory at all levels, that the necessary audits and updates have been carried out, and that all actors understand the valid applied version.

8.1.2. Documentation

Performance requirements in REN are usually one solution proposals that the authorities believe will satisfy the regulatory requirements. That solution proposal is regarded as a template, and thus, deviations of that must be documented. When the building becomes in use, this becomes crucial to verify that the building satisfies the TEK (Technical Regulations). Though insufficient documentation doesn't necessarily mean that TEK is not fulfilled, but it might indicate that the reaching of a "correct" final product could have been accidental, and that it depends on the competence of the executing party.

Deviations from the performance requirements during the construction stage (even those listed in the fire concept) could be due to the selection of cheaper alternatives for short-term economic benefits or being restricted by a tight timeframe. However, the reason is sometimes simply because of errors that are not amended due to minor chances of those being checked. Lack of supervision at the construction site results in that error.

Nevertheless, an underlying reason for deviations is the insufficient interdisciplinary communication of fire technical requirements in the construction process. A lack of knowledge among players (other than the fire engineers) can also lead to miscommunication and misunderstandings. As there is still no established joint practice in the industry among fire engineers, designers, contractors, solution selectors, and executors – this remains to be an issue.

Moreover, there isn't any clear traceability of the documentation when it comes to anomalies. In theory, when an error occurs with a certain detail at the execution level, one should be able to go back and check the description, design, and control of that specific details, but that's usually not possible. One of the reasons today why there are still many flaws and shortcoming may be the lack of supervision. If there is no real possibility that the errors will be detected, there won't be an emphasis on detection and correction of those errors – fixing takes time and costs money!

Another problem could be that the processes and requirements of fire technical documentation are not well defined. The basis for establishing a functional system that safeguards the fire requirements throughout the construction process. What we currently lack is an interdisciplinary agreement which specifically states how the processes should be achieved effectively and what the documentation needs to convey accordingly.

8.1.3. Conclusion

We can conclude that the failure of fire safety measures can take place at any given stage of the design and construction process, in which nothing suggests that one of those phases has more failure than the others. This could result that the fire safety regulations such as the ones listed in TEK and REN are not carried forward through the design, solution selection, execution, until the finished constructed project, especially due to the lack of supervision throughout all various phases. The decision on certain solutions is sometimes left completely to the executing contractor, and that could pose some major issues. Moreover, the fire technical documentation cannot be found at the construction site, making it very hard to locate when needed. Though supervision can reveal errors in traceability, it doesn't necessarily reveal those in design or execution. This calls for a need of interdisciplinary competence with supervisory personnel and continuous inspections at the construction site.

8.1.4. Recommendations

Municipalities might be required to concentrate on an increased level of supervision, both for documentation and construction inspections. Feasibility considerations might require limiting the scope of that supervision, but it should not go below a certain level. In larger projects, independent control might be the best solution, as it ensures nonbiased results and thus better supervision.

Perhaps the need for a joint interdisciplinary written guidance is arising. Such a guidance can become a common template for all different actors, thus limiting the vagueness of what is required in terms of design, descriptions, documentation of solution choices, practical and applied workmanship, control and supervision of construction, as well as control of various operations and any possibility of reconstruction or amendments. Such a guidance needs to be binding and fully agreed on by all actors.

Moreover, the choice of solutions should always take place at the design phase, and be controlled by the designers themselves, then carried out - as specified - by the executing contractors. The designers/ fire engineers will thus be the ones taking responsibility for the effectiveness of these solutions. A clear chain of responsibility is essential. If errors rise during the construction phase, the engineering firm would be the one responsible to provide detailed solutions for the problem, rather than the contractor just “winging it”.

To fully control the process, a document record for project-specific documents and drawings need to be present. This document record would include all the checked/validated documents related to this project and be available to all those involved in both the construction and supervision of the specific solutions. This should also include responsibilities of all various elements of the projects, so that could be pinned correctly upon actors. It is also very important to document the “executed” or “as built” solutions, which would also be part of the control and supervision process.

It might also be beneficial to have a unified set of technical drawings, especially for detailing works, which includes fire safety solutions along with other technical information. This would allow for easier reading of details and a holistic approach to fire safety.

9. Case studies

Below will be a list of case studies from various locations around the world, elaborating mainly how the architectural design itself can act as a catalyst to fire spread, and how easily it could've been avoided if architects had the necessary knowledge of fire dynamics, or at least managed to coordinate well enough with fire engineers.

9.1. International

9.1.1. Notre-Dame Cathedral Fire – Paris, France

The below case study focuses on the underestimation of fire risks by the responsible architects, who did not have enough knowledge of how fire progresses and spreads, and thus laid out an unsuccessful fire system, which in turn led to the destruction of a major historical masterpiece.

9.1.1.1. Overview

The architect who was supervising the fire safety systems at the cathedral, Benjamin Mouton, stated that the flame spread was widely misjudged, resulting in a much bigger fire than expected. He based his assumptions on the presence of ancient oak timbers in the attic, which are supposed to burn slowly, thus allowing for sufficient time to response action. Moreover, the detection system did not notify the fire brigades, but only issues an internal alarm. Instead, a guard was required to take a six-minute trip to inspect and report the fire accordingly (as shown in Image 2)

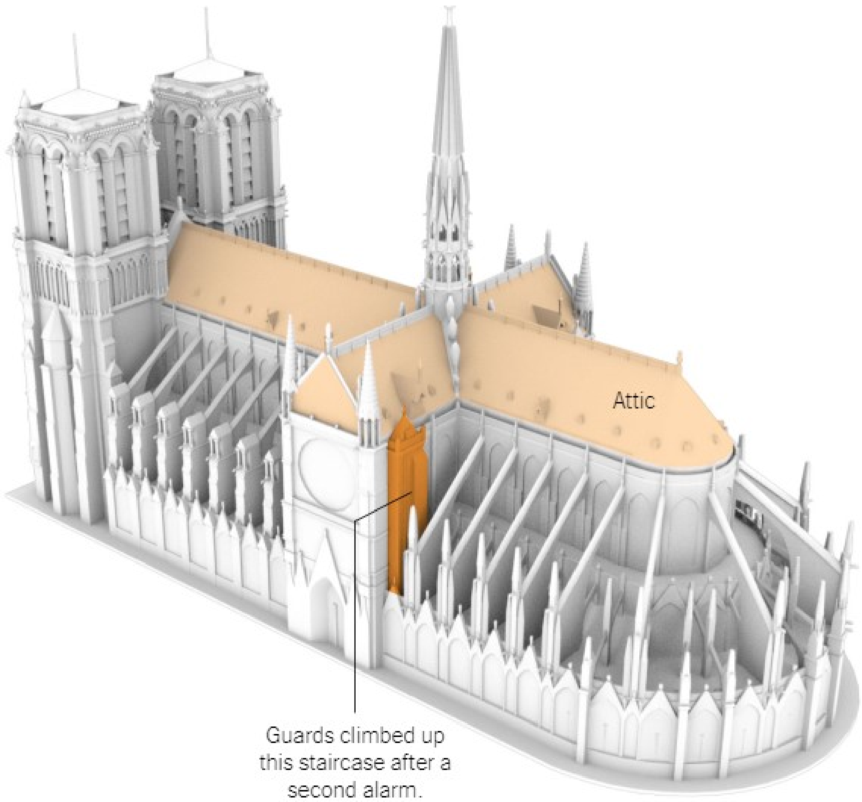

Image 2 Showing a 3D Visualization by Evan Grothjan, Karthik Patanjali and Elian Peltier

The built-in 20-minute delay; from the moment the alarm sounds until firefighters arrived and climbed to the attic; resulted in an extremely slow fire-fighting system, due to underestimation of the risk by the responsible architects. Responding guards were not allowed to notify the fire department until they climbed up and actually saw the fire.

9.1.1.2. What went wrong?

A revamp in the fire safety system was managed completely by an architect, with no financial constraints. However, protective measures such as sprinklers and fire walls were opted against as to preserve the historic structure unaltered. On one hand, the scale and complexity of the attic structure advised against using firewalls, which were considered to mutilate the structure. On the other hand, sprinklers' usage involved the risk of drowning the whole structure. Thus, prevention and detection, a conscious choice, was banked upon.

For that, two guards were continuously monitoring the roof structure, and the cathedral was equipped with smoke and heat sensors undergoing periodical checks. However, when the alarm sounded, the on-duty guard checked the area and upon seeing no obvious flames, declared that it was a false alarm, which should've been investigated. At that time, presumably, a smoldering fire had begun to spread.

Image 3 The Fire Damage at the cathedral
Image Gigarama.Ru, via Associated Press

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Benjamin Mouton’s undocumented assessment of slow fire spread in old hardwood was a major mistake. The time it takes for a thick piece of wood to burn completely is different from how quickly a fire will spread. The large surface area exerted large amounts of energy and facilitated the fire spread. By the time the guard went upstairs again to check the second alarm, the fire had already developed into immense, uncontrollable, flames. That’s when the fire brigade was informed.

The French system requires the human verification of fire alarms before notifying the fire brigades, to eliminate false alarms. However, the geometry of Notre-Dame was a major challenge, which should’ve been accounted for in the fire safety design. Perhaps, the building should’ve had an internal fire brigade, same as other buildings with the “significant risk” classification such as the Louvre and the National Library.

9.1.2. Faculty of Architecture Building, Delft University of Technology

If we assume that the building design has no effect on fire safety performance, the differences that govern the designer/fire engineer relationship are not necessarily problematic. However, that is not the case, as we will eventually deduce from the case study underneath.

The below focuses on a case which elaborates how the architectural design can have a catastrophic effect on the fire safety of a project. Fortunately, the building occupants were all evacuated safely. However, the rapid fire spread which occurred was unexpected and hindered the extinguishing efforts, eventually leading to a decision of letting the fire burn itself out, as putting it out was deemed rather impossible. The fire eventually led to the structural collapse of a large portion of the building and continued to burn afterwards. This resulted in a damage so substantial that the whole building needed to be demolished later.

Image 4 Overview of the FOA Building - Before the Fire
(Kirk, 2010)

Moreover, the architecture library, which was considered one of the finest in Europe, with an outstanding collection of architecture journals and books dating back to the 16th century, was engulfed in the fire. According to Dutch newspapers, the fire likely consumed a wealth of irreplaceable materials, such as a collection of close to 300 original chairs by masters of the early modern movement, including Gerrit Rietveld, Mart Stam, and Marcel Breuer. It also destroyed the personal archives of faculty members. (Barnstone, 2008)

9.1.2.1. Overview

The building which housed the Faculty of Architecture (FOA) was built in 1970. The building contained administrative offices, ones for faculty, staff and students. It also included classrooms, architectural studios, auditoriums, display areas, and a library. The structure encompassed a 13-storey reinforced concrete tower which sat on top of six semi-independent 3-storey structures, acting as a podium for the tower above. Image 4 below gives an overview of that.

The building was somehow irregular with an approximate height of around 57 meters. The building's layout was placed in a way in which parts of it had double height floors, especially in studio areas. Figure 15 below shows a cross section of that, in which the left part entails the single height stories and the right side with the double height ones.

Moreover, Figure 16 shows the different occupancies of each of the floors as well as the fire walls that separated the sections from each other. The middle sections were reserved for the vertical circulation (stairs and elevators), mechanical shafts, and some offices. In terms of fire safety, the building was not sprinkled, but had fire compartmentation, manual fire extinguishers and hoses, as well as a fire alarm system.

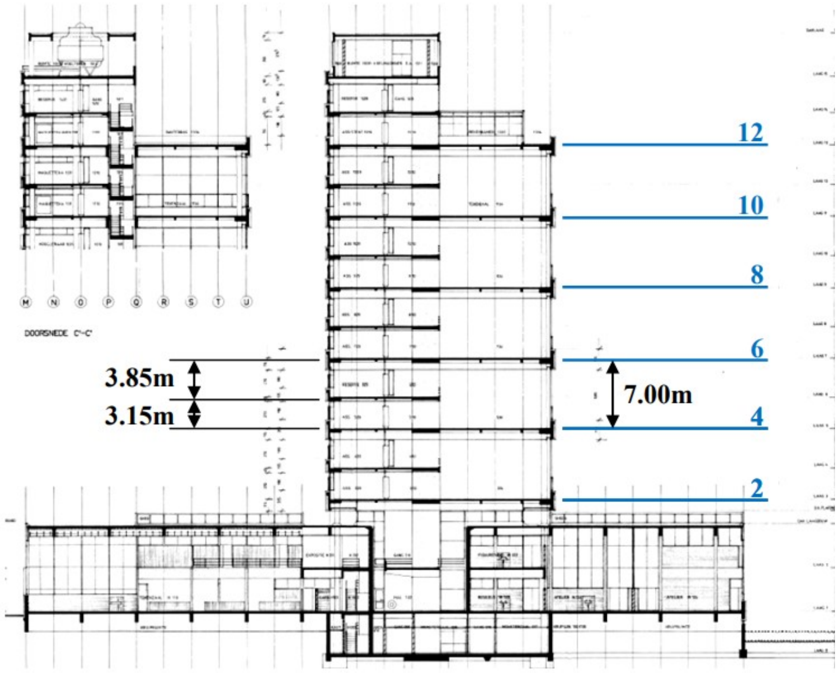

Figure 15 A cross section of the FOA building (Kirk, 2010)

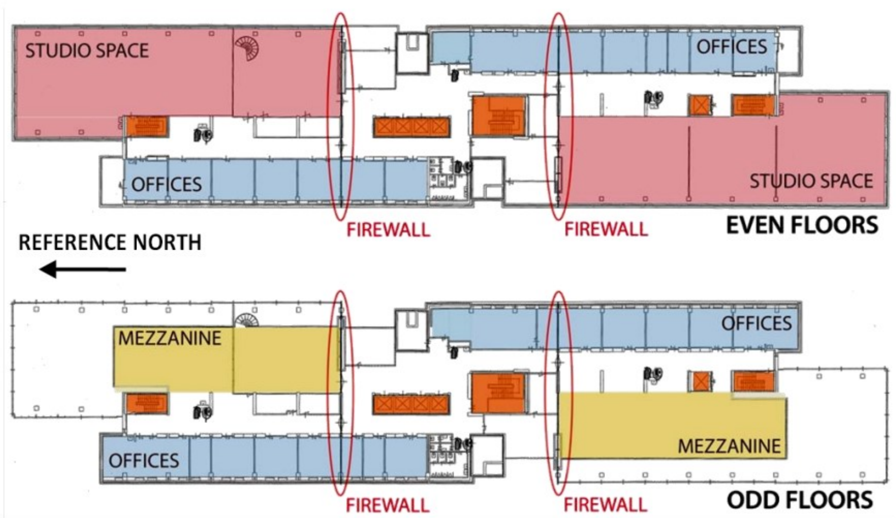

Figure 16 Showing the occupancies in different sections (Kirk, 2010)

9.1.2.2. What went wrong?

On the 13th of May 2008, the fire started when a water leak caused a coffee vending machine to spark and flame at the 6th floor of the **"code compliant"** Faculty of Architecture building at Delft University of Technology in the Netherlands. The fire quickly spread in the non-sprinklered building and the firewalls (shown in Figure 16 and Figure 17) could not contain the fire. The part which collapsed is also shown in Figure 17 with the blue dashed line, evidently quite far from the fire origin.

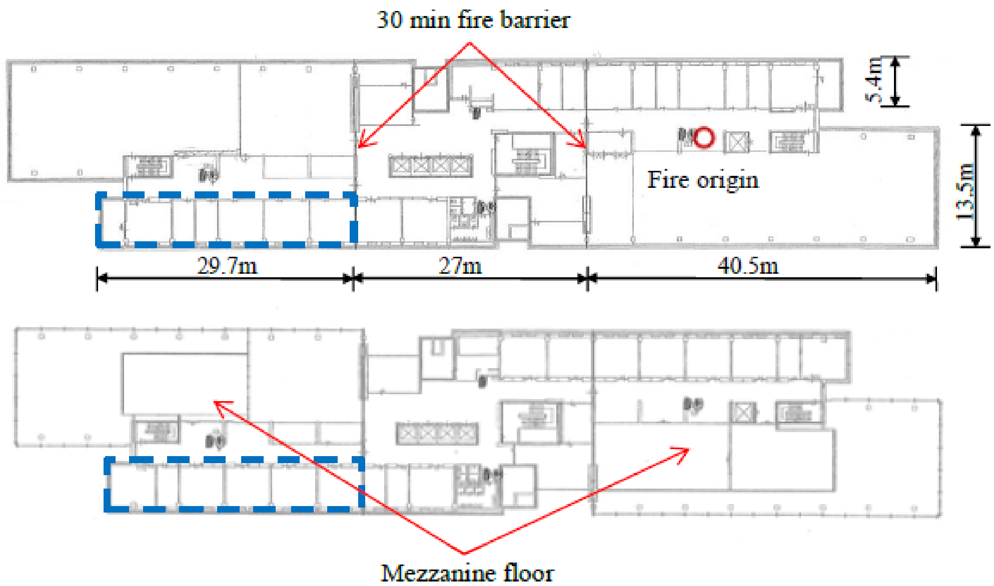

Figure 17 Showing the fire origin and the mezzanine floor locations (Park, 2014)

One of the major architectural characteristics of the building was the double height ceilings which contained the design studios. The mezzanine floor was hung from above those studios (as shown in Image 5). Moreover, for better acoustical treatment of the studio spaces, the bottom surface of the mezzanine floor was finished with acoustic ceiling panels.

Image 5 Showing the mezzanine floor (Park, 2014)

What was perplexing about this fire was that the building had a steel and concrete structure, highly fire-resistant materials, and abided completely by the building code. Thus, the vertical fire spread that occurred was definitely not expected, as the horizontal 30 minutes fire barriers were required to be able to contain the fire within its origin until it was suppressed or at least controlled. The fire spread led to the inability of fire fighters to even conduct extinguishing operations.

Image 6 During the Fire
(Kirk, 2010)

However, though it was a fully compliant structure, there were several of its features which led to the rapid fire spread and its devastating repercussions. The activities held at architectural design studios usually entail a lot of paper and cardboard drawings, modelling supplies, and other combustible materials, which should've been considered as added fuel.

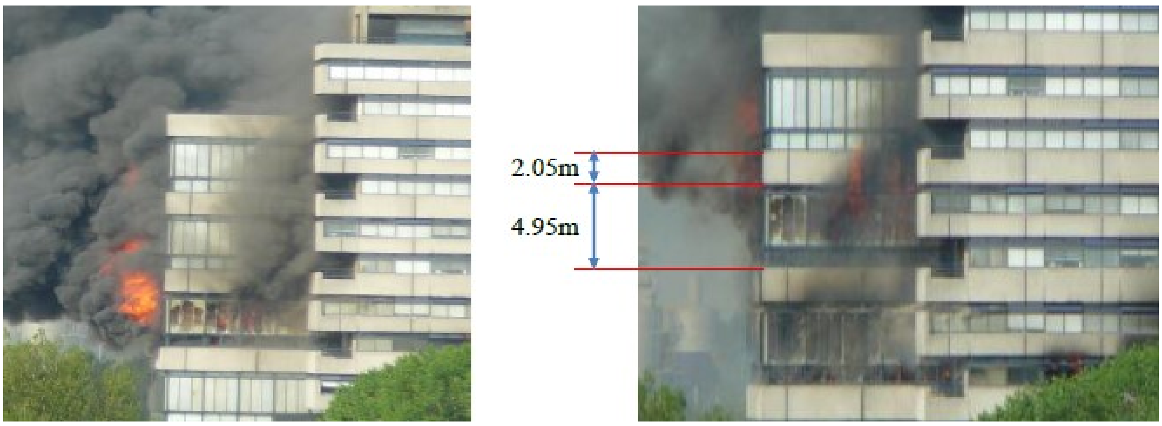

Image 7 Showing the extended flames over two stories (left) and the fast fire spread (right) 12 minutes after
(Park, 2014)

Also, the large open space of those studios allowed for enough oxygen to sustain the fire in its early stages and contribute to its speedy development. Moreover, the combustible acoustic plates which covered the bottom of the mezzanine floor highly increased the heat release rate and added radiation to the already burning fire, thus acting as an additional burner on the ceiling.

In addition, the 30-minute fire walls were not enough to contain such a rapidly developing fire, at least until the fire brigade could manage to control it. As for the external flame, the tall exterior windows (4.95 m high) facilitated the flame extension by rendering the 2.05 m of vertical separation useless. Image 7 shows how the flames spread externally, with only 12 minutes difference between the two pictures. It is worth noting that the vertical separation distance used in the building was compliant with the regulations and the prescriptive requirements. Furthermore, the continuous horizontal windows channeled the fire and propagated it across the fire barriers and around the building.

Image 8 FOA after the fire
Image by Vahid G/Flickr

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The fact that architects and fire engineers have different perspectives is quite natural, though the main goal is producing something that fits the client's requirements, the budget, and the regulations.

Thus, from an architectural perspective, the building was quite attractive. Part of that attractiveness was the continuous horizontal windows along its perimeter, as well as the hung mezzanine floor which provided a sense of spatial and visual continuity. The pilotis (pillars) on the ground floor also gave a light feeling to the massive towers above. Thus, it was a very good design from the architects' viewpoints. In 2003, and after a fire inspection, the fire safety features of the FOA were upgraded to add a fire escape, which was deemed as satisfactory to the local regulations for existing structures.

Thus, placing the blame on a specific party would be rather unjustified. Perhaps if the fire engineers had considered the additional fuel that the materials found in the design studios would entail, they would've considered the necessity of installing a sprinkler system. Nevertheless, the architects are the ones responsible for providing adequate usage of spaces and the combustible materials they would contain. Moreover, if the studies were properly done considering the large non compartmented spaces separated by non-fire-rated partitions, maybe the whole structure would've been redesigned to allow for better structural integrity in such conditions.

As a conclusion, and though there's no clear responsibility to be placed in this case, better communication and cooperation between the architects and fire engineers would've definitely been beneficial.

9.1.3. Grenfell Tower Fire – London, UK

Image 9 The Grenfell Tower post-disaster (Pasha-Robinson, 2017)

9.1.3.1. Overview

The tragedy that took the lives of over 80 people on June 14th, 2017, labeled as the deadliest fire in Britain in more than a century, has sparked major controversy about the fire safety requirements, between building regulations, approval processes, and application. The fact that lots of code changes have taken place and several different design decisions were taken resulted in a major difficulty in identifying the single point of failure.

One of those design decisions was incorporating the aluminum cladding which led to the extremely fast fire spread, a type that's not allowed to be used on tall buildings in other countries. What aggravated that was the fact that the 24-story public housing tower itself lacked several safety features, being built in the 1970s before several regulations were put in place. The tower had only one stairwell (shown in Figure 18), no sprinklers or other active suppression systems, no fire walls, and no centralized alarm systems.

9.1.3.2. What went wrong?

Installed in a 2016 renovation led by architects, the aluminum cladding covering the whole tower was the biggest problem. It was composed of a flammable polyethylene core encased by a double layer of 3mm aluminum sheets, a type of cladding usually forbidden for buildings that height, due to the fact that the increased height subsequently increases the difficulty of both extinguishing fires and evacuating occupants, and thus requires stricter safety measures.

The above could've been easily replaced with the same construction but holding a more fire-resistant core, or at least single layered zinc metal sheets. However, both of those options were ruled out for cost-effectiveness considerations, and thus value-engineered out.

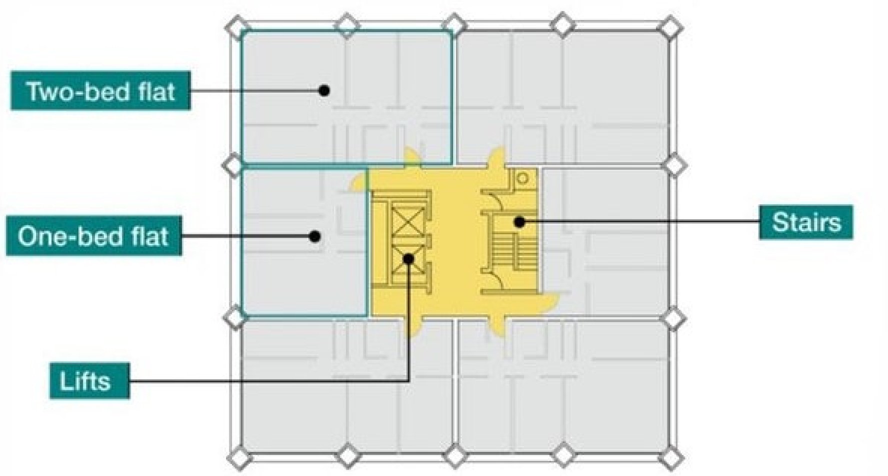

Figure 18 Typical residential floor plan of the Grenfell Tower showing the single exit staircase by Studio E Architects (Morley, 2017)

An added issue was the installation of the cladding itself. As it was retrofitted on an already existing concrete structure, there was a created airspace between the cladding and an insulation layer, which in turn created a chimney effect further escalating the fire spread speed (shown in Figure 19). A problem which could've been easily avoided if the material was properly tested before being used on a building that size.

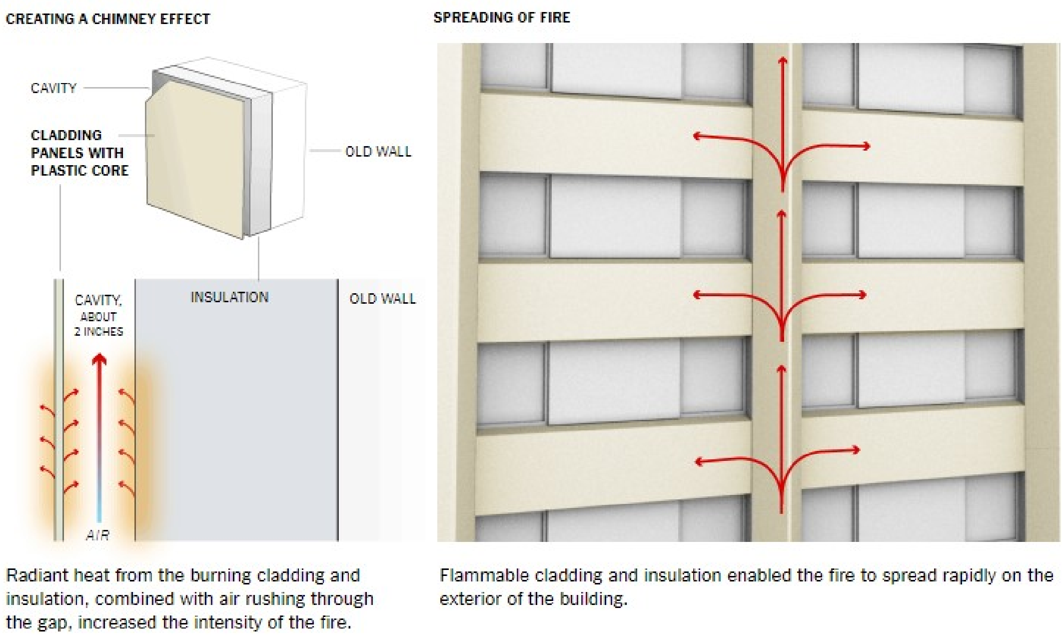

Figure 19 Image by Mika Gröndahl (Kirkpatrick, Hakim, & Glanz, 2017)

Figure 19 depicts diagrams showing the gap between the flammable aluminum cladding and the building’s insulation, which increased the fire spread. (Kirkpatrick, Hakim, & Glanz, 2017)

Normally, flames in a fire would burst out of the building’s windows, moving inside out. Grenfell tower, however, burned in reverse, as the fire spread from the exterior facades into the apartments inside, quickly filling them with toxic black smoke. Soon, the whole building was encased in a fire cylinder.

9.1.3.3. WhoΩtă blame?

The 2005 law known as the Regulatory Reform (Fire Safety) Order ended a requirement for government inspectors to certify that buildings meet fire codes and switched instead to a system of self-control.

Though the municipal government council was responsible for pressuring the contractor into reducing costs by using the cheaper but more flammable option, the process itself was entirely legal and compliant with the existing codes and regulations. Being pressured by clients into decreasing costs via using cheaper but inferior materials is an everyday struggle for architects and designers. However, the council could’ve easily afforded using more funds on providing safe public housing, though they are not expected to fully understand the dangers behind using such products.

	Post Tender Amendments: -	
B15	M&E specification changes – alternative flue manufacturer and carbon steel distribution pipework in lieu of stainless steel	-£44,094
B16	Cassette fix Aluminium cladding in lieu of Zinc cladding	-£293,368
B17	Remove louvre panel that was proposed to be located over tile and turn windows	-£60,074
B18	Pre-finished (MDF or softwood) to window board in lieu of birchwood surround	-£116,608

Table 2 Leaked document showing the local council pushing the contractors to use a cheaper cladding option; Image via The Times of London (O'Neil & Karim, 2017)

Table 2 shows a part of a leaked document of the post tender amendments showing how the option; Fireproof cladding planned for Grenfell Tower was downgraded to a less safe alternative to save £293,000, mainly by using political pressure to reduce costs. The other leaked documents demonstrated very low safety concerns. (O'Neil & Karim, 2017)

Nevertheless, the main responsibility is that of the building regulatory agencies who have allowed the unsafe usage of such products in the first place. An article in the New York Times (Kirkpatrick, Hakim, & Glanz, 2017) have repeatedly mentioned how the person in charge of drafting building safety guidelines, Brian Martin, has tried to keep limiting regulations on building products, even if fires have suggested their dangers. Using noncombustible materials for cladding was considered to “limit the choice of materials quite significantly”, and thus disregarded. Even after reports of the flammability of the panels emerged around the world, no changes took place, as the business interests were set as a priority.

Now what?

Though it wouldn't be practical for architects to second guess every safety code and regulation, the need for a holistic approach to fire safety is eminent. Even if architects are trained to focus more on the aesthetic and then functional aspects of buildings, a collaborative work between various specialists, advisory bodies, and engineers could have diverted the disaster. As, in this case, relying solely on the existing regulations proved unsuccessful.

The more knowledge designers have about the materials they're using, the more inclusive and effective their design would become. Architects are a major component of a complex system of professionals responsible for all phases of a project, a component that oversees such projects from A to Z. This gives them the advantage of being able to keep track of all the various details, thus controlling and preventing errors.

9.2. Norway

9.2.1. Mæla School – Skien, Norway


Image 10 - Mæla School Under Construction – Images by Weekly Technical Magazine (Teknisk Ukeblad)

9.2.1.1. Overview

The Mæla School project is considered as a typical architect-fire engineer conflict case, as it addresses the different priorities each of the profession has. Fortunately, the fire damage was limited.

During Construction

An article (Strande, 2007) published in 2007 labeled the Mæla School building in Skien as a scandal project. This was due to that neither the insulating material nor the façade material satisfied the requirements for fire safety. On one hand, the insulation material used lacked the properties listed previously in the documentation. On the other hand, some selected solutions for the outer wall were also undocumented. The article mentioned that the façade works were paused, as several issues were being discussed.

The issue was with the material used in the outer wall, a transparent cellulose-based insulation material. This was one of the architectural features of the project, as the material "Moniflex" releases light into the building. The variation of moniflex used was one initially used for trains, not construction projects. According to Professor Per Jostein Hoyde from NTNU, "When there is metal on both sides, the insulation will be able to contribute to the fire in other ways than when polycarbonate is used as cladding. In addition, rules for trains and buildings cannot be mixed".

After Construction

On the 17th of October 2009, 3 pupils purposefully ignited a garbage room located between two of the three separate but interconnected buildings of Mæla School. Fortunately, the fire brigade managed to extinguish the fire before it spread, which would've had catastrophic results is that was one minute later. Due to the fire, four windowpanes burst, the wood in the outer wall caught fire and the outer sheeting of polycarbonate began to melt. Had the fire brigade arrived later, the exterior plastic garment with combustible plastic insulation (Moniflex) inside would have caught fire.

Originally, there was supposed to be a thorough plastic wall with polycarbonate panels as an interior cladding in wall panels above the window level, instead of wire glazing. If that was the constructed case, the burn out time would have been 30 seconds, with catastrophic results. Moreover, had the exterior walls been built as originally planned, without adding the external sprinkler system, the total damage of the southern base was to be expected.

Image 11- Showing the 3 interconnected blocks. (Strande, 2007)

Mæla school is built in three separate buildings that are interconnected. The fire was ignited in a garbage room located between the middle and South buildings.

9.2.1.2. What went wrong?

According to the municipality, the selected fire solutions from the Pir II Architectural office was deemed unsatisfactory. Several reports were issued indicating that the facades needed to re-habilitated and rebuilt. Approved by the project group and the architects, the initial solution for the facades utilized polycarbonate sandwich walls with Moniflex plastic insulation, which the builder thought would not be approved.

Engineer Arne Olaussen, the project manager at Skien Municipality, stated that they have fire tested the original construction on a 1:1 scale, and it did not hold. Thus, the school walls had to be reconstructed, as fire safety was the main concern, especially that children were involved. Consequently, the walls were constructed according to Pir II's modified drawings and third-party controlled by Multiconsult and the fire chief in Skien Municipality.

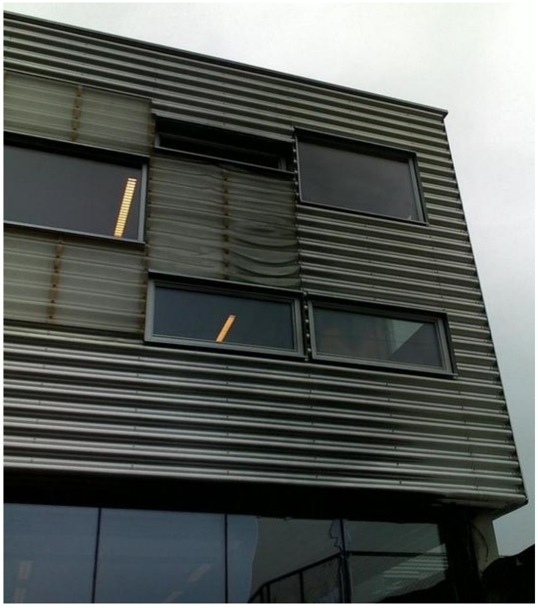

Image 12 – Showing the melted corrugated sheets (Strande, 2007)

The corrugated polycarbonate plates melted after a short time after the fire. Originally, the wall consisted of exterior and interior corrugated polycarbonate panels with Moniflex as the insulation material but was replaced with Glava and wire glazing.

Documentation Issues

According to the municipality's project manager Arne Olaussen, the execution drawings received from the architects were difficult to read and understand, besides the fact that the building technical solutions were deficient. Therefore, Multiconsult was asked to perform a third-party verification of the solutions, which led to the recommendation that those solutions were inadequate.

Multiconsult's report indicated that the risk of moisture damage to the building is large, and that the outer façade was not adequate for the usage in a school building. Olaussen stated that the documentation documents were perceived as messy engineering that was impossible to build after. Among other issues, the joints, windows, and diaphragms were projected incorrectly, which would inevitably entail major water damage to the building body.

The issue with the insulation material used was that there were no Nordic tests proving their fire suitability, only German and French tests. According to the Norwegian Building Directorate, when foreign documentation of a material is available, it is also required to be tested in Norway to verify its suitability in reference to Norwegian requirements. Thus, the light was shed on all the engineering design group consisting of Pir II architectural office, Myklebust AS, Interconsult and Agraff.

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The architectural firm considered that the problem was related to the built solutions, rather than the drawn ones, which is the responsibility of the entrepreneur and not the architect. However, the contractor has acquired the material according to the description given by the architect. The municipality was suing the whole engineering group yet regarded COWI as fire specialists but subject to the architectural firm. Thus, Skien municipality considered that the architectural firm was the one pushing for the use of flammable materials and should thus take responsibility.

On April 13th, 2010, a verdict was reached on the case, declaring that both COWI and Pir II architectural firm have been grossly negligent. Questions regarding the fire safety of the wall insulation were raised during the construction, but the municipality was eager to complete the project and put it to use. Therefore, they decided how the walls should be built and accounted for the financial expenses that this entailed. (Adolfsen, 2010)

As the product used could not be verified against the performance requirements, full-scale tests should've been carried out in approved laboratories. Thus, the documentation was highly lacking. Furthermore, deviation analysis was also almost nonexistent. According to Ramboll who were hired to try to document the exterior wall construction through calculations and analysis, there were too many uncertainties and undocumented sightings, alongside analysis errors. Among other things, the analysis does not consider the degree of ignition and the intensity of the flame and heat development.

The court's majority also concluded that Pir II architectural firm acted grossly negligent as the company had insufficient knowledge of the insulation material used in the walls. The material suggested by Pir II has never been intended by the manufacturer for construction in the way Pir II desired. Some of the mistakes made by Pir II included faulty design of cladding requirements and misclassification of fire classes. The design group assessed that the cladding materials behaved at an acceptable level during a fire. They were so light and compact that they would burn up in a very short time, thus minimizing the danger of both horizontal and vertical fire spread. Moreover, the wind turbine in the wall will also prevent the spread as it will not catch fire, besides several noncombustible sections of the walls that will also hinder fire spread. However, Image 13 below shows otherwise.

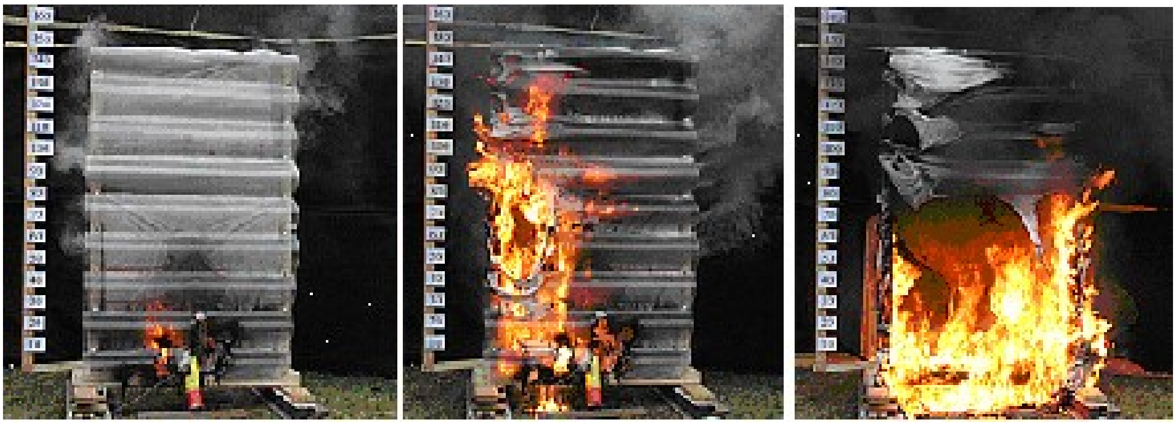

Image 13 – Showing the fire tests conducted in 2008. (Adolfsen, 2010)

In 2008, tests were conducted for an identical module with the same insulation material. The depicted fire process took 2 minutes and 10 seconds. The images above prove that there is great danger of both vertical and horizontal spread of fire.

The Final Verdict

The project group, Pir II, Cowi AS and Agraff (landscape architects) was judged to pay Skien municipality 3 million NOK. Pir II was also required to pay Skien municipality 4.5 million NOK. However, as Skien municipality was also found responsible of delaying the case in a way that designers spent many unnecessary hours on re-engineering. The court stated that after a number of redesigns, the design team managed to document solutions that fall within the requirements. Thus, Skien municipality was ruled to pay 2.4 million NOK to Pir II, 885,000 to Agraff, and 419,000 to Cowi. (Adolfsen, 2010)

9.3. Lebanon

Unfortunately, Lebanon lacks a proper system that collects data on fires and provides necessary statistics or case studies. The most that can be acquired on the subject is a couple of articles from media that cover when a major fire takes places, but nothing scientific enough to be included in this research. Though the General Directorate for Civil Defense in Lebanon is the one responsible for control of the fire brigades, they don't offer clear statistics on numbers or costs (fatalities or monetary) of fires that take place. This makes it very difficult to have an objective comparison for this research.

9.4. Conclusion

If we investigate the different case studies mentioned, the common issue is the somehow lack of knowledge and coordination between various players. Whether architects did not know enough about fire safety (such as the cases of Notre Dame and the Grenfell tower), or simply did not coordinate enough with the fire engineers and did not prioritize fire safety (as in the case of the Faculty of Architecture at Delft University and Mæla School), the results will be the same. Loss of lives will always be the main problem, and that part was disastrous in the Grenfell tower fire. Nevertheless, the loss of historically rich monuments such as Notre Dame or a library as rich as that of the FOA is also unacceptable. Fortunately, the dialogue at Mæla School commenced before the tragedy struck, which didn't have huge consequences other than material assets.

Design needs to be performed in a reassuring and safe way, from the very beginning. For that, more planning needs to be put in place. In addition, independent 3rd party inspections could be the solution, throughout the whole design and building process, and that's currently almost nonexistent. This brings us to the next chapter – Control and Supervision. How is it currently done? And what measures can be implemented to improve that?

10. Conclusion

All of the above can lead us to one main conclusion; the better the relationship among all key players of a project, the more successful that project will turn out to be. Moreover, the earlier that relationship commences and the more opinions each party is encouraged to participate with, the higher the effectiveness of that collaboration will be, eventually leading to safer, more aesthetically pleasing, environmentally friendly, and consequently more feasible projects.

Thus, if we are to be more specific within the scope of this thesis, the results would be that fire engineers should work closely with the architects at the design stage (as early as possible) to address any potential non-compliances or unsafe conditions that could lead to possible dangers from a fire inside a building or on the exterior of the building.

Fire safety design is of utmost important. Early fire and life safety input is key in building design; generally speaking, architectural compliance with the building codes should normally be achieved at the concept design stage of a project. This results in improved overall efficiency and reduced unproductive work downstream for all other disciplines within the design team.

If we are to summarize the findings into bullet points, they'd be as follows:

- Fire engineers needs to recognize architects as key players for fire safety (through their designs) and help them understand their capability, thus increasing fire safety performance through architectural design
- Adversely, fire engineers need to fully recognize the elements of architectural design that negatively affect fire safety, so they can design appropriate mitigation protection methods
- Both architects and fire engineers should have the full key elements of a holistic building fire safety performance - including but not limited to physical components, design features, occupants (including fire fighters), and fire itself – and how all these elements interact and influence each other
- Architects need to accept the presence and necessity of fire engineers, and that their intentions do not include sabotaging the functionality or aesthetics of their design, but rather creating safe environments. The sooner the collaboration takes place, the higher the effectiveness and feasibility of the project.

10.1. Research Answers

- ***Is what architects learn sufficient for them to effectively design fire safe buildings, or to at least collaborate efficiently with fire engineers?***

Architects definitely do not have the necessary knowledge to design fire safe buildings, at least not without further professional practice after graduation. However, they do have the skills to be able to collaborate effectively with fire engineers. The concept needs to be further emphasized on during their study years and later during their professional life.

- ***Will a more holistic approach to building design yield successful results? How can that be done?***

Definitely. As it was mentioned in the collaboration initiative between the BRE Centre for Fire Safety Engineering and Foster + Partners in 2011 (please refer to 1.1), such a holistic approach could be very beneficial in terms of both cost effectiveness and increased safety. The experience demonstrated the potential, and perhaps the need, for a new role in fire safety. A job which requires a comprehensive overall perspective and capability to relay specific technical information to design teams. Unfortunately, there are only a handful of individuals who have the necessary knowledge to fulfil a double role. This can also be achieved through the addition of a fire safety advisor to an existing design team. This would lay the bedrock for the consideration of various variables from the initiation of the design process, including fire safety. This, in turn, would allow designers to fundamentally, positively alter the design to produce better designs.

- ***Would the engagement of a fire engineer from the very beginning of the conceptual design be feasible? Or would that simply add unnecessary financial burdens and unwarranted billable hours?***

The engagement of a fire engineer from the early design phases can allow the design team to consult him/her on all different aspects of the project, thus detecting design errors from the beginning. This prevents expensive corrections on important aspects of the design later on, consequently saving both time and money, and not the other way around.

10.2. Recommendations

10.2.1. Education and Professional Societies

It is important that educational programs are put in place to support a multidisciplinary approach to design. For instance, a graduate diploma and a master's degree in building Fire Safety and Risk Engineering was initiated in 1992 to further train professional engineers on these matters. Afterwards, in 1996, a graduate certificate in Performance-based Building and Fire Codes was introduced to develop further skills to professionals involved in the design process, as well as those in technical areas (building approval officials, fire brigade personnel, and technical personnel from the fire protection and insurance sectors). However, these types of degrees are still quite limited, both in terms of location and frequency. Perhaps this can be introduced as some sort of professional development scheme for both architects and fire safety engineers. It might also be beneficial for industrial registration bodies to require practitioners to obtain some courses to acquire validation in their fields, the completion of the Graduate Certificate course is deemed to provide evidence of appropriate expertise in the performance-based arena. (Beck, 1997)

Through education, both architects and fire engineers need to learn more about each other's' work, priorities, and requirements. Through practice, putting both professions together in the workplace and having them work closely on projects will eventually yield more educated professionals that understand each other's requirements and can work effectively together.

10.2.2. A Holistic Approach to Fire Safety

An effective design process which efficiently leads to a successful project- a project that truly manages to fulfill all various requirements of aesthetics, functionality, safety, operability, and others – remains the main achievement that needs to be accomplished.

However, to achieve this goal, it is important to establish effective communication between the various actors as early as possible during the detailed engineering and construction phase. The purpose must be to educate all parties about the way various measures interact to eventually constitute the **holistic fire safety concept**. Design decisions taken by one of the individual actors without consulting the others, or at least understanding the aforementioned interaction, can almost definitely cause issues during the completion and the operational phases. This can also lead to the failure of the planned fire safety. Such a situation is unfortunately common and can lead to delivery and/or documentation delays, and consequently, a significant increase in costs.

10.3. Further research

The above thesis was merely the start of a research which should be done to make sure that future projects are held with a holistic approach, to fire safety and technical safety in general. A holistic approach would require the involvement of all various actors from the very beginning of the project, which would continue throughout the whole process, and perhaps extend even further.

One must invest in specialized expertise throughout all stages of a building's life cycle. This ranges from early conceptual design to construction, to usage, to ongoing and regular assessment throughout the full building life cycle. This would ensure that the original fire safety strategy is being maintained and the integrity of the buildings performance in a fire is maintained.

Thus, we would question if there is a need for adequate control and supervision of fire safety elements AFTER construction and usage of the building, besides those carried on for special fire objects? As currently, there is no way to know if the codes and regulations are actually being applied correctly, or even applied at all.

Further case studies can be an indication of whether the system would work more efficiently in that case.

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Appendices

A. Appendix A

Architects & Fire Safety Engineers; Common Grounds

As the world is steadily moving into the age of sustainability and environmental protection, working “smarter” rather than “harder” is coming into play. There will be an increasing need for professionals with a broader vision and multidisciplinary knowledge. This will be consequently saving unnecessary time, money, and efforts- thus being more sustainable. This article sheds light at methods of bridging the gap between the disciplines of architecture and fire safety engineering in the workplace, eventually reaching common grounds. Architects and fire safety engineers almost always find themselves on opposing sides, affecting both of their works’ efficiency and resulting in redundant time spent on amending designs. In some cases, the relationship between the two professions is quite faulty, as each perceives the other as trying to sabotage their work.

This article is a summary of a thesis in partial fulfillment of an MSc degree in Fire Safety Engineering at Western Norway University of Applied Sciences in Haugesund, Norway. The study concludes with the necessity of a holistic approach to architectural design. That approach will allow architects to realize the importance of involving fire safety engineers in all design phases, especially in the early design stage. Both, architects and fire safety engineers, will benefit from increased dialogue between the two professions – ultimately affecting the building design itself. Learning about each other’s’ roles in design will lead to designing functional, aesthetically pleasing, cost-effective, and ultimately safer buildings.

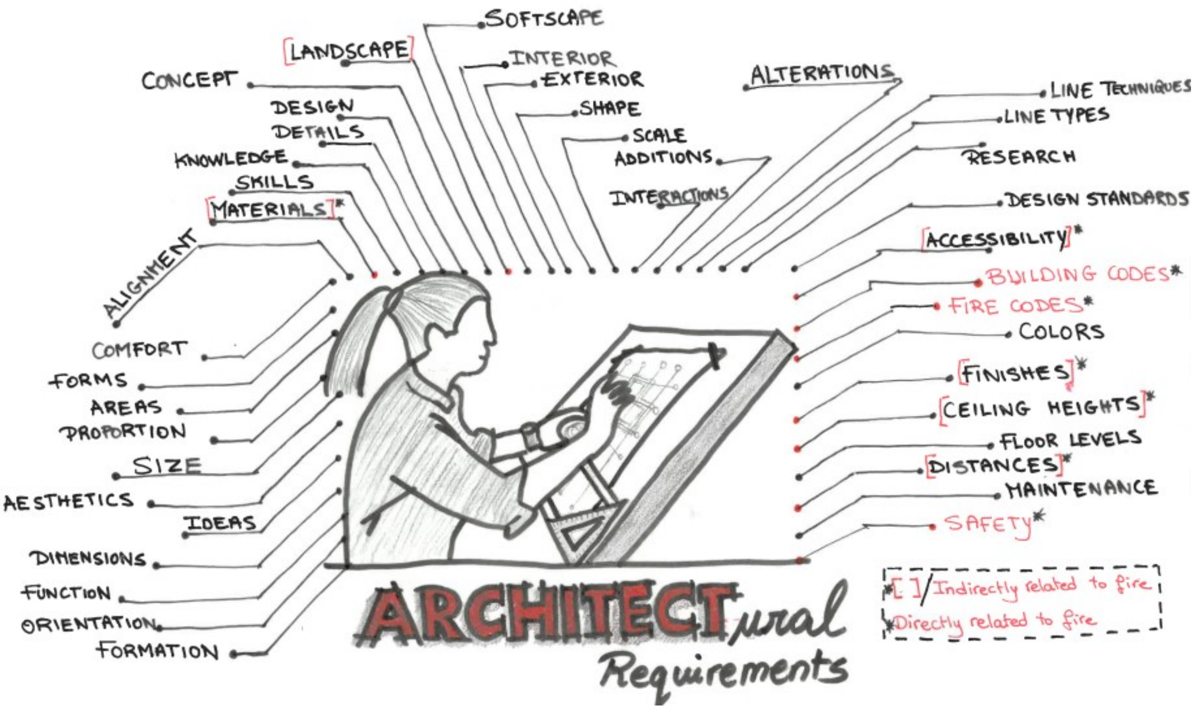

Illustration of the requirements of architectural design (self-drawn)

As architects, we tend to think aesthetically, yet always having functionality and usability in mind. This usually leads to issues with "engineering" minded people, such as civil and mechanical engineers. Studying fire safety made me realize the criticality of architectural design to fire safety just as much as other engineering disciplines. That left me questioning the connection between building design and fire safety, and thus; the relationship between architects and fire safety engineers. Even though architects tend to review main fire codes and work with fire safety engineers, the collaboration between the two disciplines is so minimal that it leads to a mis-informed and unoptimized approach to fire safety. A system that could use up some improvement.

In 2011, a collaboration initiative between the BRE Centre for Fire Safety Engineering* and Foster + Partners resulted in a member of the former joining the team of Foster + Partners in Edinburgh, UK for 8 months. His role was to aid the designers in creating inherently safer buildings in terms of fire safety. The original thought was that the fire safety engineer would solve arising fire issues for the design team. "The 'In-House Fire Safety Engineer' would become known as the 'Fire Safety Advisor' or more simply, the 'Fire Guy'." The experience demonstrated the potential, and perhaps the need, for a new role in fire safety. A job which requires a comprehensive overall perspective and capability to relay specific technical information to design teams. Unfortunately, there are only a handful of individuals who have the necessary knowledge to fulfil a double role. Thus, the addition of a fire safety advisor to an existing design team would lay the bedrock for the consideration of various variables from the initiation of the design process, including fire safety. This, in turn, would allow designers to fundamentally, positively alter the design to produce better designs. The intention is exposing architects to the concept of a holistic approach to safety requirements, including fire safety, thus allowing them to realize the importance of involving fire safety engineers in all design phases, especially in the early design stage. Both, architects and fire safety engineers, will benefit from increased dialogue between the two professions – ultimately affecting the building design itself. Learning about each other's' roles in design will lead to designing functional, aesthetically pleasing, cost-effective, and ultimately safer buildings.

Working together, architects and engineers can come up with design solutions that are better than their individual ones. Exchanging knowledge and information, especially at the early stages of a project, eventually leads to better buildings. The technical input that an engineer can provide is much more useful when improving building energy efficiency is considered. Architects might have a limited knowledge in the availability of options for fire safety design, be it prescriptive, performance based, or a mixture, besides continuous developments in fire science and simulation technologies. Furthermore, they might not be fully aware of how their different design features can affect the fire safety performance of a building.

Thus, Fire Protection Engineers should help architects understand their role in fire safety, while recognizing them as key players in that, as they could – relatively easily- embed fire safety design into their architectural approach. Architects could highly benefit from an integration of fire safety principles into their education and trainings. For instance, well distributed exits throughout a floor plan, according to location of occupancies, number of users, and occupant flow, can decrease the required egress times.

Fire safety design is of utmost important. Early fire and life safety input is key in building design; generally speaking, architectural compliance with the building codes should normally be achieved at the concept design stage of a project. Both fire engineers and architects need to recognize each other as key players in the design process, thus making sure that they essential elements of a holistic building design are fulfilled. This results in improved overall efficiency and reduced unproductive work downstream for all other disciplines within the design team. One must invest in specialized expertise throughout all stages of a building's life cycle. This ranges from early conceptual design to construction, to usage, to ongoing and regular assessment throughout the full building life cycle. This would ensure that the original fire safety strategy is being maintained and the integrity of the buildings performance in a fire is maintained.

Through education, both architects and fire engineers need to learn more about each other's' work, priorities, and requirements. Through practice, putting both professions together in the workplace and having them work closely on projects will eventually yield more educated professionals that understand each other's requirements and can work effectively together.

B. Appendix B

العدد	نوع الدراسة
92	دراسة تأثير حركة السير (Traffic Impact Study)
1,937	دراسة قوة احتمال التربة (Geotechnical Study)
351	تقارير فنية لمتانة الأبنية القائمة (Technical Reports Study)

جدول (10): عدد عقود الدراسات التكميلية المسجلة خلال العام 2017

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